Glove is in the air

Project report

Authors: Øyvind Bø Syrstad, Erik Rogstad, Trond Valen, Frode Ingebrigtsen, Lars-Erik Bjørk, Stein Jakob Nordbø
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Executive summary

Glove is in the air is a project carried out as part of the course TDT4290 Customer Driven Project at Institute of Informatics and Computer Science, NTNU, during the autumn 2004. There are six project members, all from class SIF2, Computer Science. The customer for for this project is the Chemometrics and Bioinformatics Group at the Institute of Chemistry, NTNU. Their goal is development of a library for integration with the software data analysis tool *SciCraft*. In addition, the customer wants an application demonstrating the capabilities of this library.

The purpose of *Glisa* is to enable a pair of electronic gloves to be used for control of virtual reality applications, and it should support both movement and rotation of either hand, as well as measurements of finger flexure. The intended use of these gloves, and the library, is to enable interaction with a virtual environment without using conventional input devices like keyboard and mice. In particular, the customer envisioned integration with *SciCraft* to perform tasks such as molecule building and interaction with plots from analysis of large sets of data. The demonstration application is supposed to build confidence in that gloves as input devices would be a helpful addition to 3D applications.

In order to determine the needs of the customer and the best way to fulfill these, a prestudy has been conducted. The prestudy revealed that the functionality of the library would need to span from basic communication with the input devices to advanced features such as gesture recognition. Moreover, it became evident that the demonstration application should display a virtual environment scene and enable the user to use the gloves to manipulate objects in this scene.

The prestudy lead to a software requirements specification that made up the foundation for system design, implementation and testing. At the end of the project, a library has been created that enables interaction with a 3D scene, and that forms the foundation for further research and development, towards a final integration with *SciCraft*.

Lars–Erik Bjørk

Frode Ingebrigtsen

Stein Jakob Nordbø

Erik Rogstad

Trond Valen

Øyvind Bø Syrstad

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Part I

Project Directive

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Chapter 1

Introduction

The project directive is a document whose intention is to regulate the administrative side of the project and offer guidelines on how it is to be carried out. The document is dynamic and should reflect administrative changes throughout the project.

The project directive is divided into the following succeeding chapters:

- Chapter 2 - The project charter, which presents the project facts.
- Chapter 3 - The project plan, which presents the activities and time schedule of the project.
- Chapter 4 - Organization, which contains information regarding the team structure.
- Chapter 5 - Templates and standards, which provides project standards that will ensure document consistency.
- Chapter 6 - Version control, which introduces the software used for version control of the project.
- Chapter 7 - Project follow up, which documents the proposed procedures to maintain project progress.
- Chapter 8 - Quality Assurance, which aims to document procedures to ensure project quality.
- Chapter 9 - Test documentation, which describes the testing routines for the project.

Chapter 2

Project charter

The project charter is an agreement between the customer and the project group that summarizes the concepts of the project.

2.1 Project name

The name of the project is *Glove is in the Air*, as is the name of the end product. The short version of the name, to use when referring to the product, is *Glisa*.

2.2 Employer

Bjørn K. Alsberg at the Institute of Chemistry, NTNU.

2.3 Stakeholders

The following were identified to be the main stakeholders of the project:

- Project group
- Customer
- Tutors

The full list of names with contact details can be found in Appendix C.

2.4 Background

This project is carried out as a part of the course *TDT4290 Customer Driven Project*, which forms a part of the Master of Computer Science Program at NTNU. The objectives of this course are to enhance student's practical knowledge by carrying out all phases of a real project for a given customer. The students participating in this course were randomly divided into groups and given random projects.

The customer in our particular project is the Chemometrics Group at the Institute of Chemistry at NTNU. They have caught interest in the use of virtual reality (VR) as a tool for inspecting complicated data. In accordance with the objectives they have given us, we are determined to develop and document a communication interface between a demo application and the virtual reality gloves. Depending on the quality of the product they intend to use this for future integration with their existing *SciCraft* data analyzing tool (www.scicraft.org), where they wish to use the virtual gloves to control objects.

2.5 Output objectives

The overall objective of the project is to develop a library that can be used by the SciCraft software as an interface to the virtual gloves somewhere in the future. This will lead to the possibility of using virtual gloves as a more intuitive and user-friendly approach to manipulating data. This is especially meant to ease the handling and understanding of complex 3D-rendered molecules and to achieve a closer interaction between analysis and visualization.

2.6 Result objectives

The overall purpose of the project should be realized through the following result oriented goals:

- Develop low-level drivers to the data gloves and *Flock of Birds*.
- Develop a middleware library that allows the gloves to interact with 3D-objects in a VR environment.
- Develop a demonstration program that shows the functionality of the library.

2.7 Purpose

The Chemometrics group uses a VR laboratory to visualize statistical plots and molecule structures in three dimensions using passive stereo. Since this technology requires light from the projectors to pass through polarisation filters, the lights in the lab will typically be dimmed to make the projected

image appear clearer, thus making keyboard interaction with the computer less feasible. Moreover, keyboard interaction is not very intuitive and requires extensive training to be efficient.

It is the purpose of this project to create a library for communication with virtual gloves allowing intuitive rotation and manipulation of three dimensional data. This data mainpulation will be realised through hand gestures and postures from data glove input devices, which will replace textual and mouse input.

2.8 Feasibility of the project

There are several reasons to why this project is interesting and feasible both technologically, operationally and commercially.

2.8.1 Technological viability

Since no non-commercial software of this kind is known, a software development project is required for making *SciCraft* VR-enabled. The lower level software which connects to hardware devices is to be written in C++. This is a language that is well established and for which compilers exist for most platforms, in case a later project is established to port the software to a different platform. The rest of the library shall be developed in Python, which represents a higher level of abstraction and thus hopefully less and more readable code.

2.8.2 Operational viability

Using data gloves to manipulate data is much more intuitive than using a keyboard, and presumably more efficient as well, since humans from birth are trained to use their hands to manipulate their surroundings. The time required for training will also be less than if complex mouse- and keyboard commands are to be learned.

2.8.3 Commercial viability

The project is required to release all sources under GPL, so the program cannot be sold commercially. However, Institute of Chemistry may get an advantage from being technologically ahead of other institutions when competing for the best students and researchers.

2.9 Scope of the project

The scope of the project is defined by the bullet points stated above in section 2.6. A detailed description of the work breakdown structure (WBS) is documented in section 3.3.1. The overall

phases are as follows:

- Planning
- Prestudy
- Requirements specification
- Construction
- Implementation
- Testing
- Evaluation
- Presentation

These phases are further broken down into appropriate tasks that are carried out in order to reach the overall goals. Each phase is documented and the documents are to be approved by the customer.

Concrete deliveries, in addition to the phase documents, which define the scope of the project are:

- Source code for the library.
- API-documentation for the library.
- Design documentation.
- Source code for the demonstration application.
- Phase documents and final project report.
- Oral presentation and practical demonstration of the project results.

2.10 External conditions

The following conditions are predetermined and must be considered throughout the project:

- SubVersion should be used as version control system.
- The system must run on Debian Unstable.
- The demonstration program should use Visualization Toolkit (VTK) and Qt/PyQT.
- C++ and/or Python should be used as developing tools.
- All low-level drivers should be independent of VTK.
- Documentation is required and must be written in English and in LaTeX format.
- All code should be open source GNU Public Licensed (GPL)

2.11 Budget

Each project member is estimated to work 24 hours per week in 12 weeks and 3 days, which approximately results in 305 hours on the project. The total number of hours estimated for the project will then be 1830. As this project is carried out as part of the course *TDT4290 Customer Driven Project*, no salaries or money are involved.

2.12 Deliveries

Important dates for the project:

- August 24th, 2004: Project start.
- October 28th, 2004: Pre delivery of pre study report and requirement specification.
- November 18th, 2004: Presentation and delivery of final report.

Chapter 3

Project plan

This section will provide an overview of the phase activities and milestones of the project along with the work breakdown structure.

3.1 Success criteria

These defined success criteria will be used during the project evaluation to determine the project success:

- The low-level communication library is implemented, tested and found functionally complete with respect to the features of the hardware.
- The middleware providing higher-level functions responds to simple hand gestures and reports picking and movement events.
- The demo application clearly presents the system functionality.

3.2 Risks

These risks were immediately identified during the project planning:

- The middleware recognising gestures constitutes a technology risk, as the project's success is dependent on that the construction/adaption of suitable algorithms is successful.
- Given the exploratory nature of the project, it is vital that the gathering of requirements from the customer is done thoroughly. However, even when sufficient attention is directed at getting the requirements correct during the requirement gathering phase, the customer may later change his mind, introducing delays and new difficulties into the project – in the worst case rendering the entire design obsolete.

The projects' factors of risk are further elaborated in appendix D

3.3 Work breakdown structure

This section will clarify the work breakdown structure of the entire project.

3.3.1 High level project activities

The project has been divided into eight main phases, where the estimated percentage of total project time is given in the brackets:

- Planning (11%)
- Pre study (19%)
- Requirement specification (12%)
- Construction (12%)
- Implementation (20%)
- Testing (8%)
- Evaluation (2%)
- Presentation (3%)

This makes up 87 % of the total project time, whereas the rest of the time is estimated for project management, lectures and self study. A more detailed overview of the project activities is provided in appendix A.

3.3.2 Activity relationships

The relationships between the activities can be read from the Gantt-diagram in appendix A. They are intended to be carried out in a quite sequential manner, with some overlap, meaning that some resources could be allocated to a subsequent phase while others complete the preceding phase. Between the construction and implementation phase, this kind of overlap would lead to an incremental development. Some testing will be carried out during the requirement specification and implementation phases, while a full system test and usability confirmation test will be done during the testing phase. The project evaluation and presentation will be standalone phases at the end of the project and will be done after completion of the final report.

3.3.3 Required skills

The skills the group members are required to possess to complete this project are:

- The project coordinator must have skills in project management, in addition to the technical demands of the project.
- The delivered library is required to be written i C++ and Python, and it is necessary that the group's members know or learn this language.
- All documentation is to be written with the LaTeX type-setting system, and knowledge of how to document using LaTeX is therefore a requirement to all group members.

3.3.4 Activity schedule

See figures A.1 to A.10 in appendix A for project activities and Gantt diagrams of the different phases.

Chapter 4

Organization

This chapter will provide a brief overview of the group structure within the project team.

Each member of the project team has been assigned one or more roles that defines their main area of responsibility. Although a project leader has been assigned under the role name *project coordinator*, the authority hierarchy in the group is rather flat. This is meant in the sense that the project coordinator is responsible for the project progress, but the process of decision making is carried out in democracy.

The main roles of the project along with the group members responsible for each one of them are stated in table 4.1.

Project coordinator	Erik	Makes sure the project follows the planned progression
Document keeper	Trond	Responsible for gathering, organizing and filing of all documents
Lead Programmer	Stein Jakob	Must keep a system in all source code, and ensure that all code conventions are carried out
Design	Øyvind	Must ensure that the overall design of the project meets the requirements stated in the requirements specification
Quality assurance	Lars-Erik	Will create and follow up on routines that should guarantee the quality of the end product
Customer contact	Frode	Sustain communication with the customer
Timekeeper	Øyvind	Will keep track of the time schedule for all group members and compare estimated time with actual time spent
Tester	Frode	In charge of testing throughout the project

Table 4.1: Project roles

Chapter 5

Templates and standards

The following templates and standards are to be used to ensure consistency for all documents throughout the project.

5.1 Templates

Templates for summons, minutes and status report are established in order to standardize these documents, which are reproduced every week. The templates can be found in appendix B. As for phase documents, this project directive will serve as the template.

5.2 File naming and directory structure

This section provides file naming conventions and directory structure for the project documentation.

5.2.1 General file naming conventions

File names must not contain blank spaces and must be named with the correct file type suffix which is described in section 5.2.1.1 - 5.2.1.3.

5.2.1.1 Internal documents:

This naming convention should be applied to documents for minutes, status reports and summons, respectively:

- minutes_category of meeting_yymmdd
- statusreport_yymmdd
- summons_yymmdd

5.2.1.2 Project directive:

The main document will be project_directive, the parts of the document will be stored in files named as follows:
charter, project_plan, organisation, templates, version_control, project_follow_up, quality_assurance, test_plan.

5.2.1.3 Phase documents:

The phase documents will be named as follows:
project_directive, prestudy, requirements_specification, construction, implementation, test_documentation, evaluation, presentation.

5.2.2 Directory structure:

documentation/: All the documentation in our project, that is everything but source code and executable files
source/: Source code and executable files
documentation/internal/: All internal documentation, not included in the report
documentation/report/: The report, that is the final, textual deliverable
documentation/internal/minutes/: Minutes from meetings, in .tex format
documentation/internal/status/: Weekly status reports, in .tex format
documentation/internal/summons/: Summons for meetings, in .tex format
documentation/templates/: Stand-alone templates for status reports, minutes and summons, as opposed to those that are included in the project directive
source/doc/: The API documentation for specific source files
source/lib/: Drivers and libraries
source/bin/: Executable, binary files
source/src/: Source code files

documentation/report/ will be divided into sub directories according to the chapters of the project report. The chapters will consist of the project directive, the phases and more, to be defined.
The project directive directory will also be divided into directory for each of its components.

5.2.3 E-mails

When files are sent to the tutors the extension _kpro11 is added to the file names to ease their process of keeping track of files from different groups. All e-mails sent to the tutors and the customer should also include the [kpro11] prefix in the subject field.

Chapter 6

Version control

In accordance with given customer demands, *SubVersion* is used for version control of code. We have no experience with other version control systems, and prefer to stick with one standard. Therefore SubVersion is also used for version control of documents.

We have a SubVersion repository configured at one of the group members home directory at vier.idi.ntnu.no. Further file and directory structure of the repository is explained under directory structure in section 5.2.2.

In addition all phase documents are to be marked with the version number and date in order to ensure version-correctness for external readers.

All documentation files are stored in *SubVersion* as .tex files as changes are frequently made and can be directly edited into the .tex files. All internal documents, completed phase documents and individual parts in phase documents are also compiled into .pdf format and communicated through *It's learning*, in appropriate folders.

Chapter 7

Project follow up

The sections of this chapter are to ensure the follow up and progress of the project.

7.1 Meetings

We have scheduled weekly meetings on Mondays for the group internally and with our tutors. Customer meetings are also scheduled on Mondays, when needed. See templates for summons in appendix B.

7.1.1 Tutor meetings

We have scheduled weekly meetings with our tutors 1015-1100 on Mondays in room IT458. The weekly status report is discussed and approved, along with the previous minute, current phase documents, and other questions about the project process that has occurred.

7.1.2 Customer meetings

We have meetings with the customer when we need to discuss or clarify certain questions. These meetings will primarily be held on Mondays from 1115-1200 at the Institute of Chemistry.

7.1.3 Internal meetings

We have internal meetings every Monday to discuss the status, plan the upcoming activities, divide tasks etc. The meeting is from 1115-1200 if we do not have a customer meeting, otherwise from 1215-1300 in room IT458. We write minutes and use an agenda for our internal meetings as well as the ”external” ones in order to document what has been decided and keep an acceptable efficiency.

7.2 Internal reporting

We report the status on weekly hours along with the degree of completion of activities and weekly milestones. The status will be discussed on the weekly internal meetings. The hours used from Thursday 00:00 to Thursday 00:00 must be reported to the timekeeper before 00:00 every Thursday.

7.3 Status reporting

We report a written weekly status to our tutors and customer that is sent along with the summons. See the templates in appendix B.

7.4 Project management

We are using the TROKK model of project management and discuss it in every tutor meeting as a part of the status report, see Appendix B. TROKK are the capital letters of the model's constituents, in Norwegian. We use the term TROKK here since we will use this model in Norwegian, although we describe it in English in this document.

- Time(no:Tid): Are we in schedule according to planned milestones and activities?
- Risk(no:Risiko): What are the risks that threaten the project? What is the likelihood and consequences of them striking, and what will be done if a risk strikes? Who's in charge of handling the specific risks? See the risk table in appendix D.
- Scope(no:Omfang): How much are we able to produce? Will we have to leave out or add some functionality, due to lack of time or changes in the customer requirements?
- Cost(no:Kostnad): In our project, cost will be used in the sense of working-hours, since no money is flowing in our project. Is the group efficient? Estimated versus spent time? This would really be important in a real working situation, where the workers are actually paid for the hours they spend on the project and fines are often agreed upon if the project team fail to deliver on time.
- Quality(no:Kvalitet): Will we have to reduce the product's quality for some reason?

Chapter 8

Quality assurance

This chapters aims for ensuring the quality of both the end product and the administration of the project. Routines are described for various tasks and more will be added continuously as they are needed.

8.1 Response times with the customer

The following response times were agreed upon with the customer:

- Approval of minutes from the last customer meeting: Within 48 hours after minutes is sent to the customer.
- Feedback on phase documents sent to the user for review: On the coming customer meeting.
- Approval of phase documents: Within 48 hours.
- Answering questions: Within 48 hours.
- Put forward documents: Reply within 48 hours and forward documents when located.

8.2 Routines for producing quality from the start

In orders to stress the importance of producing quality from the start, the following routines are worked out:

- Close cooperation with the customer
- Strict report writing to ensure correct requirements
- All group members are responsible for the quality of their own work and accountable for possible errors

8.3 Routines for approval of phase documents

1. The group gathers to review the documents internally and a copy is simultaneously reviewed by the tutors.
2. After the internal approval and feedback from the tutors the phase documents are sent to the customer by e-mail
3. The customer approves the documents, possibly gives feedback within agreed response time
4. The group revises the phase documents
5. Back to pt.1

8.4 Calling a meeting with the customer

1. Proposal for summons is to be sent by e-mail to all group members within 48 hours before it is to be sent to the customer
2. All group members should respond within 18 hours to present their views
3. Possible changes are made, and the final summons is sent to the group member responsible for customer relations
4. The group member responsible for customer relations sends the summons to the customer, tutor assistant and all group members by e-mail at latest at 12:00 the day before the meeting

8.5 Reports from the customer meetings

1. Proposal for report is to be sent by e-mail to all group members within 12:00 the day after the meeting
2. All group members should respond within 12 hours to present their views
3. Possible changes are made, and the final report is sent to the group member responsible for customer relations
4. The group member responsible for customer relations sends the report to the customer and all group members by e-mail at latest at 16:00 two days after the meeting took place

8.6 Calling a meeting with the tutors

1. Proposal for summons is to be sent by e-mail to all group members before 12:00 the day before it is to be sent to the tutors
2. All group members should respond within 12 hours to present their views
3. Possible changes are made, and the final summons is sent to the tutors and all group members by e-mail at latest 12:00 the day before the meeting

8.7 Agenda for meetings with the tutors

1. Approval of the agenda
2. Approval of report from the last meeting with the tutors
3. Comments on report from the last meeting with the customer
4. Approval of status report
5. Walkthrough/Approval of enclosed phase documents
6. Other topics

8.8 Report from the last meeting with the tutors

1. Proposal for report is to be sent by e-mail to all group members within 12:00 the day after the meeting
2. All group members should respond within 12 hours to present their views
3. Possible changes are made, and the final report is enclosed with the summons for the next meeting

8.9 Routines for the distribution of information and documentation

A web-page is to be published at 'It's:learning'. All information/documentation is to be referred to from this page. If the information/documentation is available on the Internet, a hyperlink is to be placed at the published web-side together with a brief summary of its contents. If the information/documentation is only available in a non-electronic form, the web-page should refer to were the information/documentation is physically placed.

8.10 Routines for registering costs (working-hours)

Every week all group members are to report their working hours for the previous week. A working week ranges from Thursday 00:00 to Thursday 00:00 the following week. The report should be delivered to the group member responsible for registering working hours. Which task is worked on and the current overall phase are also to be registered along with the working hours. The report should be delivered as a spreadsheet that is open office compatible.

Chapter 9

Test documentation

This section describes the testing routines the project will use, and when the different tests will be carried out.

9.1 Module test

Goal

The goal of this test is to eliminate all errors in the individual modules of the system.

How to test

A test plan should be written for the testing of each module and they should mainly focus on testing whether or not the different modules meet the requirements stated in the requirements specification.

When

Since the different modules will be defined in the construction phase of the project, a test plan for each module should also be in made in the construction phase. The test itself should be executed in the implementation phase immediately after the completion of each module.

Responsibilities

- **Test plans:** Stein Jakob
- **Execution:** The implementors of each module

- **Evaluation:** Frode

9.2 System test

Goal

The idea of the system test is to check if all the modules work together to produce the expected results.

How to test

In this test the complete product should be tested. It is supposed to find errors in the integration of the individual modules, so errors in the modules it selves should not occur in this test phase. Again the test result should be compared to the requirements specification to determine if the system meets the expected results.

When

A test plan can be written concurrent with the development of the requirements specification. It should ensure that all requirements are tested.

Responsibilities

- **Test plans:** Frode
- **Execution:** Entire group
- **Evaluation:** Øyvind and Frode

9.3 Usability test

Goal

The test should show if the finished system is working in an intuitive way for the end user.

How to test

The entire system with the demo application should be used in this test. Most programming errors should already have been eliminated in the module tests and the system test. Standard usability testing techniques should be used, with several test persons who are not already familiar with the system.

When

The test plan should be developed together with the requirements specification and executed in the testing phase after the system test.

Responsibilities

- **Test plans:** Frode
- **Execution:** Entire group
- **Evaluation:** Erik and Trond

Part II

Prestudy

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Chapter 10

Introduction

This is the prestudy document of group 11 in the course *TDT4290 Customer driven project*. The group is carrying out a project for the Chemometrics Group at the Institute of Chemistry at NTNU. The project is established with the objective of developing a library with which to connect virtual reality gloves with their existing data analyzing tool *SciCraft*.

The purpose of this phase is to extend our knowledge regarding existing technology and business processes within the customer environment, and explore compatible technologies in the market that we can make efficient use of in order to address the requirements given. Potential solutions will be sketched based on this knowledge and assessed against given evaluation criteria. This evaluation will assist us in reaching a final conclusion on the most suitable solutions for the project.

Some of the topics described in this document have a very technical nature and some parts may be affected by technical language and terms. We are however confident that the document is written in a form understandable for our customer, who are familiar with most of these expressions.

The prestudy document is divided into the following succeeding chapters:

- Chapter 11 - Description of the customer, which provides a brief overview of the customer and their position in the organization.
- Chapter 12 - Glove is in the air - what is it?, which provides a description the project.
- Chapter 13 - Operational requirements, which states the operational requirements set for the project.
- Chapter 14 - Evaluation criteria, which provides criteria of which to evaluate different solutions against.
- Chapter 15 - Theory, which introduces the area of technology we will operate in during the project.
- Chapter 16 - Description of existing system, which describes SciCraft and the devices we intend to use in the project.
- Chapter 17 - Alternative solutions, which describes the different solutions we have looked at along with an evaluation of them. Development tools are also evaluated in this chapter.

- Chapter 18 - Conclusion, which presents the different choices of solutions.

Chapter 11

Description of the customer

The project Glove is in the Air (Glisa) is assigned from the Chemometrics and Bioinformatics Group (CBG) at the Institute of Chemistry at Norwegian University of Technology and Science (NTNU) in Trondheim, and the customer contact person is Bjørn K. Alsberg.

The following sections will provide a brief overview over the whole organization of Norwegian University of Technology and Science (NTNU) and a small group called the Chemometrics and Bioinformatics Group under the Institute of Chemistry.

11.1 NTNU

NTNU was established January 1st, 1996 by a restructuring and renaming of the University of Trondheim (UNiT) and The Norwegian University of Technology (NTH). Today approximately 20000 students are enrolled at NTNU and half of them are undertaking technical degrees. The whole organization of NTNU has an annual budget of 2.8 billion kr.

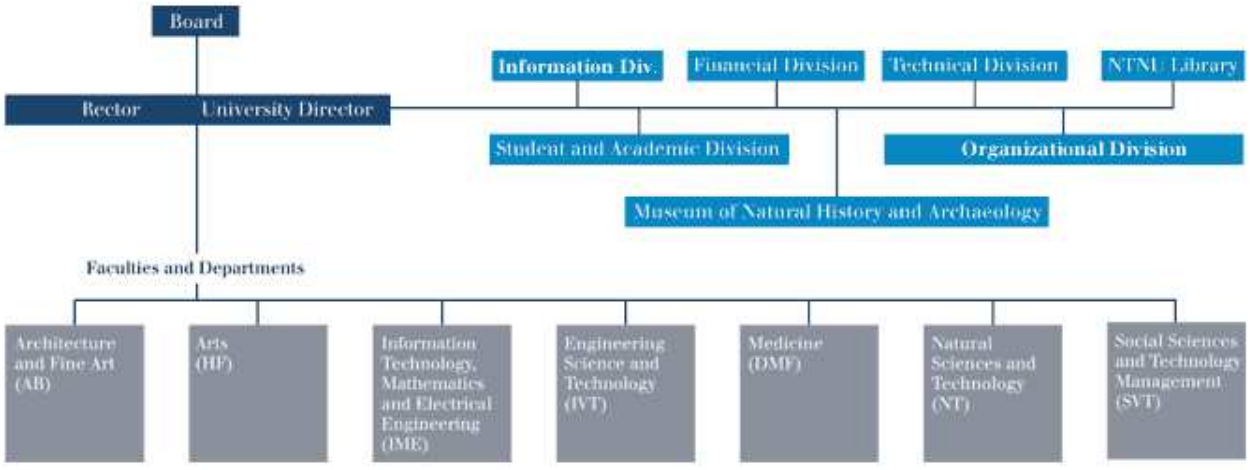

Figure 11.1: Organization chart of NTNU [Dah04]

NTNU is controlled through a board and the headmaster is the leader of the board. The organization is further divided into seven faculties and 53 institutes as shown in figure 11.1 above, where the Institute of Chemistry is incorporated under the Faculty of Natural Science and Technology.

The next section will describe the actual customer, which is a part of the NTNU organization.

11.2 The Chemometrics and Bioinformatics Group

As stated above, CBG is located under the Institute of Chemistry at the Faculty of Natural Science and Technology. CBG is a part of FUGE bioinformatics platform branch in Trondheim, which is one of the big programs of the Norwegian research council, within functional gene research.

The primary focus of CBG is to develop new data analytical methods within the fields of chemometrics and bioinformatics. Within chemometrics they are, according to [CG04] particularly interested in:

- Efficient representations of spectra
- Hyperspectral image analysis
- Quantitative structure-activity relationships
- Drug design

Within bioinformatics they focus on:

- Simulation of microarrays
- Methods for gene selection
- Gene ontology as background information
- Finding comparable protein spots in gels
- Whole cell fingerprinting

Additionally CBG provides free data analysis through their NTNU Data Analysis Centre (NDC) and an open source data analysis software called *SciCraft* is under development.

Chapter 12

Glove is in the air - what is it?

As mentioned in the previous chapter this project is carried out as a part of the course *TDT4290 Customer Driven Project*, which is integrated in the Master of Computer Science program with the Chemometrics and Bioinformatics Group (CBG) as our customer.

The customer is mainly focused around data analysis methods, and the data analysis tool *SciCraft* is already under development. As of today, this system is mainly based on 2D graphics with keyboard and mouse as the key input devices. The intention of this project is to introduce virtual reality(VR) gloves into data analysis software by creating low level communication between the system and the VR gloves, and integrate the gloves with the existing software to some extent. Handling 3D data through the use of virtual gloves is more intuitive than through textual and menu based commands, and if gestures are implemented in a correct manner they can serve as basis for very user friendly and powerful data analysis. Another obvious advantage of enabling gestures handling is that these 3D operations are carried out in a VR lab, with lights turned off and 3D glasses put on. Handling the keyboard in such a setting is challenging. A future integration with *SciCraft* will also improve the data analysis as increasing visualization implies increasing insight.

Although we have a common understanding with the customer that the main priority is to get the *5DT Data Glove 5* (see section 16.2) to function properly, we want to make this as compatible as possible with the existing *SciCraft* data analysing tool. The low level communication and integration with *Flock of Birds* (see section 16.3) will form the basis, but beyond that we want to develop a well defined middleware that supports gestures. Additionally we will develop an illustrative demo application showing the possibilities within the area of data gloves and virtual reality.

Chapter 13

Operational requirements

These chapter provides operational requirements, which is an overall description of what functionality our product will offer. These requirements can be seen as an elaboration of the result objectives stated in the project charter. Below follows the list of operational requirements, which will further be broken down into functional and non-functional requirements in the requirement specification phase.

Operational requirements:

1. Make support for low level communication between the existing system and virtual reality gloves. All low level drivers should be independent of any graphics library.
2. Make instructions from the user to the computer keyboard-independent.
3. Develop a middleware library that allows the virtual reality gloves to interact with 3D-objects in a VR environment.
4. Make a demo application showing the virtual gloves' functionality.
5. Enable SciCraft developers to integrate this 3D virtual reality into SciCraft.

It is common practice in system engineering projects to determine the business requirements as well as the operational requirements. However, Glisa is not a traditional system engineering project in the sense of developing an application to enhance the business processes of the customer. The result of this project is supposed to be integrated into SciCraft by CBG and the end result of that process will hopefully benefit the business processes of those making use of the end system. As business requirements relates to the work routines surrounding the software system, in our case, SciCraft is not widely in use yet, and few routines are defined for the system. Our focus in this project is therefore future integration with SciCraft rather than determining the business processes of future end users of the system.

Chapter 14

Evaluation criteria

During the prestudy phase we have looked at different solutions of which to approach the project. Some of them were discarded during the preliminary sorting, but the most interesting solutions had to be assessed against given evaluation criteria to distinguish them and conclude the most optimal solution. This chapter will present these evaluation criteria.

Glove is in the Air (Glisa) will be a system that operates at different levels. From the nature of the project we can argue that the end product should be divided into three layers:

Firstly, in *Glove is in the Air (Glisa)* we are concerned with issues ranging from reading signals from Human Computer Interaction (HCI) devices through a serial port, to interpreting these signals, to visualization in 3D.
Secondly, there is an essential requirement of modularity, since our product will be integrated in the *SciCraft* tool for interactive data analysis and will be further developed by the *SciCraft* team. The hardware support of the HCI devices and the interpretation of the hardware input signals is what will be integrated into *SciCraft*. In addition, we are required to produce a demo application that shows what our module is capable of.
Naturally, we will need a clear cut interface between the demo application and the rest, so that the developers taking over our product will not have to pry it apart. Clearly separating the reading of hardware signals and the interpretation of them, is believed to ease the development process, both for ourselves and for the *SciCraft team*.
Although the layers of *Glisa* will not be completely defined before the construction phase, we can from these conditions already separate layers that the end product must consist of:

- Low level drivers: This layer will do all communication with the HCI devices used.
- Middleware layer: This part of the system will probably do all gesture recognition and also allow devices to be used in 3D applications.
- Application with 3D visualization: This layer will use the middleware to control a 3D environment.

It is clear that each layer needs different solutions, and the requirements for the solutions varies with the layers. We will now define the evaluation criteria used to assess the different solutions of the different layers in chapter 17.

14.1 Evaluation criteria for low level drivers

The solutions for low level drivers are assessed against the following evaluation criteria:

- How difficult it will be to implement the solution in our system.
- The amount of work required to learn how the solution functions.
- How compatible the solution is with the GNU General Public License (GPL).
- The estimated overall quality of the solution.
- How dependent our project will be on 3^{rd} parties by using the solution.
- How accessible the source code of the solution is.

14.2 Evaluation criteria for the middleware level

The solutions for the middleware level are assessed against the following evaluation criteria:

- How new gestures are introduced to the system.
- The computational complexity of the system.
- The recognition rate of the system.
- Whether the system is able to successfully recognise gestures performed continuously.
- Flexibility concerning finger positions and movements in the recognition process.

These criteria are further elaborated in section 17.2.2.

14.3 Evaluation criteria for application level (graphics package)

The solution for the graphics package in the application layer is assessed against the following evalution criteria:

- Does the package have a Python binding?
- Is the package already in use in *SciCraft* (VTK)?
- Is the package on a high conceptual level?
- Does the package have a good estimated overall quality?

These criteria are explained in section 17.3.2.

Chapter 15

Theory

This chapter provides a brief description of virtual reality, 3D display devices and Human Computer Interaction (HCI) devices. Understanding these terms is essential for our particular project and they are therefore explained in some detail. This is useful background information for the succeeding chapters, which describes technical matters and concrete systems concerned with these terms.

15.1 Virtual reality

As computers have evolved, simple number crunching is not the only application available. Visualization is one of the areas of use that has become an enormous aid for scientists, making interpretation of large amounts of data intuitive and easy. One of the most recent applications of visualization, is virtual reality(VR). Unlike other computer visualization, virtual reality tries to make an illusion of being inside a scene, and not only an outside spectator. Users can interact with objects, and get immediate response. Virtual reality has also found its way to the entertainment industry, as many games today gives a first person perspective of 3D scenes.

15.2 Display devices

There exists numerous different VR display systems. The most basic one, is an ordinary computer 2D-display, which provides no real 3D view, but can emulate 3D with use of perspective projection. Since every desktop computer has a display, a wide range of applications supports simple virtual reality on 2D displays. There also exists advanced special built VR systems which use ordinary 2D displays for projection with good result. The good results are an effect of the human interpretation of visual impressions. When the objects are far away, the human eye only sees a 2D image, since triangulation is not possible. The distance to objects, are then determined by empiri and perspective, so regular 2D displays works just as good as 3D displays. Typical special built VR systems using 2D displays are simulators, such as flight simulators, naval simulators and car simulators.

Many of the more advanced VR applications use real 3D projection. There are many different systems, but they all use the technique of stereo vision, where each eye gets presented a slightly

different image. In this way, it is possible to emulate the natural triangulation humans do on objects close to the eyes(typically $< 5m$). There are numerous different implementation of stereo vision virtual reality solutions. From head displays, to large installations where images are projected on the walls and on the floor.

One easy way of obtaining stereo vision is by using two projectors with polarization filters, so that a viewer can experience stereo vision by wearing polarization glasses. It is called passive stereo, and exploit the fact that light waves are waves with different polarization. By adding different polarization filters in front of the projector, it is possible to see the light emitted from one projector when you use a corresponding polarization filter in front of an eye. A drawback of polarization, is that the light intensity degrades, since a polarization filter only let parts of the total amount of light trough.

Another way of experience stereo vision, is by a method called active stereo. In active stereo projections, only one projector is needed, but the glasses is far more advanced and expensive than passive stereo glasses. Active stereo uses time slots when displaying images for the eyes. In one time slot, an image for the left eye is shown, in the other time slot, a image for the right eye is shown. The glasses are responsible for letting light trough and blocking it, alternately. A timing device is therefore required, and that is often solved with radio receivers in the glasses, so active stereo glasses is often prized high. Another problem is that a high refresh rate of the projector is critical, since the refresh rate experienced by each eye, is half of total refresh rate.

Many graphic packages support stereo projection today. OpenGL, a widely used graphics library that is implemented on a wide range of systems, is one of them.

15.3 Human computer interface devices

Virtual reality allows people to interact with the computers in a very intuitive way, and HCI interfaces in virtual reality often tries to copy natural real world tools, such as a steering wheel. Data gloves is another interface that is used. Data gloves allow a virtual reality application to take input from the users hand, which enables the user to manipulate objects like he/she does in the real world.

There are HCI devices with and without feedback. Feedback that can be sensed through the hand (or another part operating a HCI device), is called tactile feedback. Although HCI-interfaces with tactile feedback are getting more common, their price is often to high, even for small companies, and are still considered high-end products. Exceptions exist, and especially in computer gaming, devices with tactile feedback are common. Joysticks and steering wheels are available, with affordable prizes.

Chapter 16

Description of the existing system

An open source software for interactive data analysis called *SciCraft* is already developed at Chemometrics and Bioinformatics Group (CBG). They have set up a 3D lab where they want to use *SciCraft* in a virtual reality environment. This means that the graphics will be displayed in 3D and the user will interact with the program with his/her hands directly on the displayed graphics. To achieve this interaction, CBG have aquired a pair of virtual gloves, named *5DT Data Gloves 5* and a device called *Flock of Birds* that can be used to measure position of two sensors attached one on each hand. At present time, *SciCraft* is already capable of displaying 3D graphics, but no work has been done to allow the gloves or *Flock of Birds* to be used in interaction with the program. Jahn Otto Andersen, which is a technical consultant concerned with our project, has developed a small library called *Hololib* for communication with *Flock of Birds* and a home made virtual glove. He has also developed an application called *Holomol* to demonstrate some of the possibilites use of these devices can provide. In this chapter we will go into detail of these existing systems.

In chemistry, computations on molecules is a frequent task of work. There exists programs today, which may aid help to work process, but the functionality is often limited. In interviews with Bjørn K. Alsberg, we have been told that much of the work is done in a tedious and unintuitive way, since building of molecules is done with a computer mouse. After a computation, there is often need for restructuring of the molecules, which again is done with the computer mouse. The team at the chemistry lab have constructed *SciCraft*, hoping to improve this situation.

16.1 SciCraft

SciCraft is a software tool for manipulating and representing data, in various user defined ways. The main objects in SciCraft are nodes which can have multiple tasks. The main nodes are input nodes, function nodes and plotting nodes. These are linked together in various ways to manipulate the data, and together they form a diagram. Each node has input ports and output ports and are interconnected through these. The input nodes typically reads data from a file. There may be several input nodes in a diagram.

The function nodes perform operations on the data, for example filtering, mathematical operations. The functions may be programmed by the user to suit the user's needs and must be programmed in

one of the following programming languages:

- Octave
- Python
- R

To integrate user-programmed functions in SciCraft, there must be created a .zml-file describing the function's arguments, input and output. The format of a .zml-file is much like an .xml-file and is called .zml because *SciCraft* was earlier named *Zherlock*. The function arguments are hardcoded by the user, while the input is the data flowing through the links, linking the function nodes to the rest of the diagram. The output is what the node produces to the rest of the diagram.

The plot nodes are used to represent the data. The two main plotting-nodes are 3D-plot and 2D-plot. In the plotting nodes the user may manually manipulate the data, by removing, moving or adding values. This project aims for improving the user's interaction with the 3D-plot.

16.2 5DT Data Glove 5

This is a brief description of the different features of the *5DT Data Glove 5*, which our customer intends to use in combination with their data analysis tool *SciCraft*. It will explain the technical details of the gloves, and provide a brief walkthrough of the driver. The most technical details are provided in appendix G, consisting of resolution of output data, computer interface, data transfer and basic driver functions.

16.2.1 Introduction

The *5DT Data Glove 5* is a glove equipped with sensors to measure finger flexure as well as pitch and roll of a users hand. Domains of use are primarily virtual reality applications. The glove consists of a lycraglove, with flexure sensors build into the fingers. On the top of the hand, there is a box where all the sensors are connected. From the box, there is a wire attached to the computer. The tilt sensor is also attached to the box.

16.2.2 Gestures and mouse emulation

The *5DT Data Glove 5* has built-in hardware support for gestures and mouse emulation. The finger flexure measurement and gesture recognition/mouse emulation requires the glove to be in different states. It is not supported by left hand gloves either.

16.2.3 Driver

The manufacturer provides a proprietary driver for *5DT Data Glove 5*. Versions for both Windows and Linux exist. The C header file which is shipped with the driver, provides function prototypes for a range of useful functions. The driver also supports software recognition of gestures. See appendix G for the basic functions of the driver.

16.2.4 Usability of driver

The proprietary driver provides sufficient functionality for most applications. The documentation of the driver is also good. The Linux version comes with a shared libary file and a header file, and no source is available as far as we can tell. The fact that the driver is precompiled, and not open source, could make difficulties with migration between systems.

16.3 Flock of Birds

Flock of Birds is a hardware system for motion and position tracking with multiple sensors, delivered by Ascension Technology Corporation, Ascension-Tech for short. The system can register the position and orientation of multiple sensors in space. In our setting, the sensors will be used to track the motion of the VR gloves at the Chemistry lab. Our customer at the Institute of Chemistry has already purchased this product, so we are required to use this system in our project. This introduction to *Flock of Birds* is based upon Ascension-Tech's *Flock of Birds* manual [Cor02]. Technical specifications and basic commands for controlling the system can be found in appendix H.

16.3.1 How it works

The *Flock of Birds* consists of bird units which each control a sensor and possibly a transmitter. From a physical point of view the birds are boxes with their own internal computer and ports to connect with a sensor, a transmitter and other bird units. The birds are interconnected via a *Fast Bird Bus (FBB)* inter-unit cable. The *Flock of Birds* needs at least one transmitter, generating a pulsed DC magnetic field which is sensed simultaneously by the Bird unit sensors. Each bird unit calculates its sensor's position and orientation relative to the transmitter. All bird units may be connfigured to report their position and orientation simultaneously to the host computer. The *Flock of Birds* uses the serial port on the host computer.

One, and only one, of the birds is the master bird. All other birds are slaves, and can only speak when spoken to by the master or the host computer. The transmitter(s) may be connected to the master or to a slave, in which case the master tells the slave to turn on its transmitter. The master bird has its own sensor as other birds. One may use an extended range controller to provide better accuracy when the sensors are far from the transmitter. In this case the master unit is typically not one of the birds, but an extended range controller dedicated to controlling the transmitter, with no sensors attached. All other birds will then necessarily be slaves of the extended range controller.

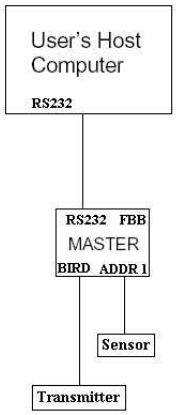

Figure 16.1: The existing configuration of *Flock of Birds* at the Institute of Chemistry

16.3.2 Controlling the birds

The birds are controlled using commands specified in the *Flock of Birds* documentation. The bird units may be addressed through dedicated cables from the host computer using the RS-232 interface, or via the master bird. The birds are given unique addresses on the *FBB*, the master has the address 1. When controlled via the master, the address is used in the command, otherwise we don't need it. There is also a reserved broadcast address, to address all birds at once. A summary of the basic commands is provided in appendix H.

16.3.3 The existing system

Until now a single provisional glove has been used as a VR glove. A single master bird is used, being connected to both a standard transmitter and a sensor, which is attached to the glove. This setup (fig. 16.1) is called a stand-alone setup in the *Flock of Birds* documentation. Communication with one glove is supported in *Hololib*, the library that our customer has written and used. A demo application has been written, which shows simple interaction with the glove. This demo lets the user work on a 3D demo molecule, adding, deleting and moving atoms around within the molecule.

16.3.4 The desired system

We wish to use *Flock of Birds* with two *5DT Data Glove 5*s. We will use a master bird unit connected to a sensor and a standard transmitter. This sensor will be attached to the right hand glove, referred to as the master glove. The slave bird will be connected to a sensor on the left hand glove, referred to as the slave glove. The customer requires us to use a RS-232 interface on the host-to-master cable and a FBB inter-unit cable between the master bird and the slave bird. This setup is described in fig. 16.2.

If the customer decides to purchase an extended range transmitter one day, a different setup is required. An extended range controller will be the master unit, controlling the extended range

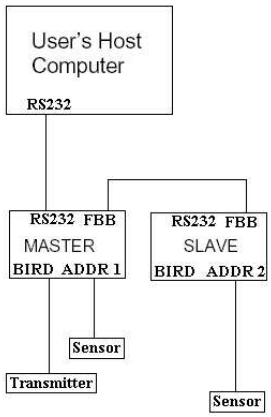

Figure 16.2: The desired configuration of *Flock of Birds* at the Institute of Chemistry

transmitter only. Two bird units are used, each one connected to a sensor for each glove.

16.4 Hololib

Hololib is a library for basic communication with VR-interfaces. It only supports *Flock of Birds (FOB)* and a mockup VR-glove. The code tree of *Hololib* which is used today, will probably never support any other devices. Reuse of the name however, is possible, as extended functionality is needed in *SciCraft*.

16.4.1 The mockup VR-glove

The VR-glove has two sensors. Sensors are simple wires with contact points connected to the middle- and index finger. On the thumb, there is some aluminum foil attached to a wire. When the contact points on index- and middle finger or both touches the aluminum foil, a circuit is closed, and picking is registered. Data is transferred trough the parallel port interface. A sensor for *Flock of Birds* is also attached to the glove.

16.4.2 Functionality

Hololib provides a class for serial communication to support *Flock of Birds*. The parallel port communication used for talking to the VR-glove, is coded inside a class named `HoloPicker`. The `HoloPicker` class also implements all other functionality of the VR-glove. *Flock of Birds* needs calibration before use, so *Hololib* implements an algorithm that is used for calibration. Besides the functionality just mentioned, *Hololib* is limited. The code does not seem to be made for future use, as there is no good interface for programmers to use. However, *Hololib* could be useful in the sense of learning, as much of the functionality needs to be implemented in our project, but with a more intuitive design.

Chapter 17

Alternative solutions

In search of possible solutions for our system we have divided our focus according to the layer organization suggested in chapter 14. This chapter describes the different solutions we found, and does an evaluation to determine which solutions can be usable in our project. Alternative solutions to drivers for communication with the Human Computer Interaction (HCI) devices are explored first, followed by a section where the middleware layer is discussed and in particular different methods for gesture recognition. Last is an evaluation of 3D graphics packages in the application layer of the end product. As one of the external requirements for our project is that it must be written in *Python* or *C++*, we have also included a short description and evaluation of these programming languages.

17.1 Low level drivers

In this section we will describe an external solution for the low level drivers and variations of this solution against self-made solutions.

17.1.1 Description of low level drivers

The purpose of low level drivers is to handle all communication with the HCI devices. The solutions we have considered are the following:

1. Create the drivers ourselves and use what we can from *Hololib*.
2. Use drivers supplied by manufacturers of the HCI devices.
3. Use the entire *VR Juggler* suite.
4. Use only *Gadgeteer* from the VR Juggler suite.
5. Extract the drivers that can be found in *Gadgeteer* and maintain them independent of the *VR Juggler* project.

Component	Description
Gadgeteer	Provides drivers to input devices and abstractions of input data, to hide which specific device is used. It is also possible to configure devices through this package.
Tweek	A *Java* GUI that can be connected to the rest of a VR Juggler application to provide a control panel.
JCCL	A library for configuring and monitoring *VR Juggler* applications.
Sonix	An interface that can be used to add sound to *VR Juggler* applications.
VR Juggler Portable Runtime	A runtime environment that runs on top of the operation system. All *VR Juggler* applications are run as objects in this environments. It provides abstractions for normal operating system services like threads, synchronization, sockets and I/O.
VR Juggler	The package that glues all the other packages together.
PyJuggler	Makes it possible to use *VR Juggler* application objects written in the *Python* programming language.

Table 17.1: The components of *VR Juggler*

A description of *Hololib* can be found in section 16.4. Section 16.2 and section 16.3 includes descriptions of the drivers supplied by the manufacturers for the *5DT Data Gloves 5* and *Flock of Birds*.

VR Juggler

VR Juggler is a platform for development of virtual reality applications that has support for a wide range of input devices, special displays and 3D sound systems. It is divided into several parts, with each part serving one particular purpose in the system, as shown in table 17.1. The complete architecture of the *VR Juggler* suite can be found in figure 17.1. The entire suite is developed at Iowa State University and is released as open source under GPL. For more information on *VR Juggler*, see [Tea04c]

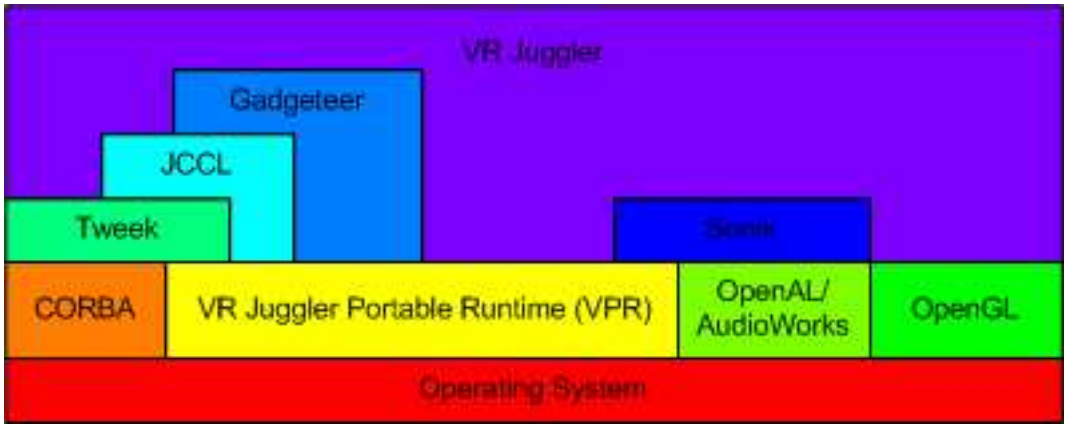

Figure 17.1: The architecture of *VR Juggler* (source: [Tea04a]

Gadgeteer The most interesting part, for our use, of the *VR Juggler* suite, seems to be Gadgeteer. It includes drivers for a wide range of HCI devices found in table 17.2, with promises on the home page of more devices being added to the list in upcoming releases. Of the devices supported are of

course the *5DT Data Glove 5* and *FOB* of most interest since these are the devices we are actually supposed to use in this project. One possibility is to only use one or both of the drivers for these devices, and not use anything else of Gadgeteer or *VR Juggler*. Another option is to use more of the Gadgeteer package. This could add value to the project by allowing the software to use Virtual Reality (VR) gloves of other brands than *5DT Data Glove 5*, and possibly other position devices than *FOB*. Of course the price of this value would probably mean higher complexity in the development, and in particular the process of seperating *Gadgeteer* from *VR Juggler* could turn out to be difficult.

Other issues One of the problems with using libraries developed by 3^{rd} parties is the risk of being dependent on software we have no control over. And while the fact that *VR Juggler* is developed at a university gives confidence in the project, the *VR Juggler* suite still seems quite unfinished. A look at the project page on SourceForge.net (see [Tea04b]) reveals that only 13 developers are registered for a project with very wide goals. This makes the project voulnerable for people leaving the project and could cause it to eventually become unmantained. Another issue is that some parts of the software seems somewhat unfinished. The Gadgeteer package has still not hit a version 1.0 release, in fact the only way to get the source code to *Gadgeteer* is to manually check it out from their CVS repository. There have obviously been some focus on documenting *VR Juggler*, but the documentation is not complete and blank sections can be found in the documentation that already exists.

- Ascension Flock of Birds
- Ascension MotionStar
- Fakespace PinchGloves
- 5DT DataGlove
- ImmersionTech IBox
- Intersense IS-900 and the Intersense Interface Library SDK
- Polhemus Fastrak
- Trackd and the TrackdAPI
- USB and game port joysticks on Linux
- U.S. Digital serial encoders (for measuring Barco Baron display angles)
- VRPN

Table 17.2: List of devices supported by Gadgeteer (source: [Tea04a])

Pros and cons summarized This section lists possible advantages and disadvantages with using some part of the VR Juggler suite in our project.

Pros:

- Portability - *VR Juggler* can be run a large number of platforms

- It will probably be easier to include support for other brands and also other types of HCI devices.
- The source code is already there, which means that we can concentrate on adding more value to other parts of the system.
- GPL means that we can copy and modify the source code as much as we want, as long as our project remains under GPL.
- As *VR Juggler* is open source, a lot a the code has probably already been tested, which could mean fewer programming errors.

Cons:

- We would become dependent on a 3^{rd} party product.
- *VR Juggler* does not appear as a finished product.
- It could turn out difficult to separate individual drivers or parts of *VR Juggler* from the rest of the suite. This is mainly because of the virtual machine normal applications written for *VR Juggler* use.
- The entire *VR Juggler* suite is quite complex and a lot of it seems useless to us at the present time.

17.1.2 Evaluation of solutions for low level drivers

This section compares the different options we have in choosing which low level drivers to use in our project. The options defined are the following:

1. Create the drivers ourselves and use what we can from *Hololib*.
2. Use drivers supplied by manufacturers of HCI devices.
3. Use the entire *VR Juggler* suite.
4. Use only *Gadgeteer* from the VR Juggler suite.
5. Extract the drivers that can be found in *Gadgeteer* and maintain them independent of the *VR Juggler* project.

The next sections summarizes characteristics of each option, and is followed by the comparission of all options.

17.1.2.1 Create the drivers ourselves

- Writing all from scratch gives full controll over the system. No external depedencies is needed besides basic C-functions.

- Time consuming. There is a more than a good chance that the project will go over the estimated 1830 hours. The complexity may also be too much to handle.
- No licencing problems. We choose what licence the product shall be released under.
- We can use some of the code from *Hololib*, and use the advantage that we have access to the person who wrote that particular code.

17.1.2.2 Using drivers from manufacturers

- Both *Flock of Birds* and *5DT Data Glove* have drivers from the manufacturer available. The drivers are belived to function very well, considering their origin. *Flock of Birds* drivers are provided as source files, and some tweeking is believed to be done before we can use them.
- Drivers for low level communication allowes us to focus on developing a good intermediate interface, and a good demo application.
- The drivers are proprietary and closed code (but free of charge), so they can not be included in a GPL release. Although they can not be included in the release, GPL programs can depend on them, so we can separate our own code from the drivers, from a licencing point of view.
- We will not have the possibility to modify the drivers or repair programming errors since we do not have access to the source code.

17.1.2.3 Use the entire *VR Juggler* suite

- Since *VR Juggler* is a large project developed for VR applications, it's possible that we could use it for functions beyond the drivers.
- *VR Juggler* provides abstract input types, so changing between different types and brands of equipment is easier.
- It supports cross platform integration.
- No licencing conflicts as *VR Juggler* is released under *GPL*.

17.1.2.4 Use only *Gadgeteer* from the *VR Juggler* suite

- If we were to use only *Gadgeteer* we would have to do some modifications as it depends on the virtual machine embedded in the *VR Juggler* suite. This could mean that we would lose the cross platform independency inherent in *VR Juggler*.
- We would still have the support for devices of other types.

17.1.2.5 Extract only drivers from *Gadgeteer*

- By using this option we would have to copy the drivers from *Gadgeteer* to our own source tree. This gives the advantage that we have control of the source code.

- A lot of work would have to be done to remove dependencies in the drivers to other parts of *Gadgeteer* and *VR Juggler*.

17.1.2.6 Comparison charts of the different options

To decide on an option, we have defined a set of evaluation criteria and added weight to each criteria regarding the importance we think it has for our project. Table 17.3 shows the criteria with the weights ranging from 1 to 10, with 1 being the least important and 10 being the most important.

Criteria	**Weight**
No licencing conflicts	3
Full access to source code	2
Doesn't have to maintain drivers ourselves	5
Cross platform compability	4
Independence of 3rd parties	3
Easy to implement	9
Ease of learning	8
Estimated quality of drivers	7

Table 17.3: Evaluation criteria and assigned weights

In table 17.4 we've set a value for each option for every criterion after how well we feel the option is meeting the criterion, with values ranging from 1 to 5. Higher number means that the solution meets the criterion to a higher degree.

	Drivers from scratch	Drivers from manufacturers	VR Juggler suite	Gadgeteer	Only drivers from Gadgeteer
No licencing conflicts	5	1	4	4	4
Full access to source code	5	1	3	3	4
Doesn't have to maintain drivers ourselves	1	5	4	4	2
Cross platform compability	3	3	4	2	2
Independence of 3rd parties	5	2	1	1	3
Easy to implement	1	4	2	3	2
Ease of learning	2	5	1	2	2
Estimated quality of drivers	3	5	2	2	2

Table 17.4: Chart of how well the options meet the evaluation criteria

By multiplying each value in table 17.4 to the correct weight in table 17.3 we get the weighted values in 17.5 with the sum at the bottom.

	Drivers from scratch	Drivers from manufacturers	VR Juggler suite	Gadgeteer	Only drivers from Gadgeteer
No licencing conflicts	15	3	12	12	12
Full access to source code	10	2	6	6	8
Must maintain drivers ourselves	5	25	20	20	10
Cross platform compability	12	12	16	8	8
Independence of 3rd parties	15	6	3	3	9
Amount of work required in impl.	9	36	18	27	18
Ease of learning	16	40	8	16	16
Estimated quality of drivers	21	35	14	14	14
Sum:	103	159	97	96	95

Table 17.5: The weighted values

We can see that using drivers from manufacturers scores the best in the comparison. The final choice of low level driver solution is described in chapter 18.

17.2 The middleware

This chapter describes different alternatives for building the middleware layer (mostly the gesture recognition part), evaluation criteria for choosing the most fitting alternative, and a discussion of the different approaches to the problem. We consider implementing the chosen solution ourselves to be a great task, so an external library that implements the chosen solution is evaluated. In appendix F.1 we elaborate the chosen solution to form a foundation for more specific requirements gathering, design and implementation.

17.2.1 Introduction

A gesture-based interface is a human-computer interface where the system is controlled by using physical actions or movements. In our system, these will be captured by a data glove (from *5DT*) and a positioning device (called the *Flock of Birds*). Gestures are expressive motions and differ between individual users. Nevertheless, it is a goal for the system to reliably classify gestures and avoid misclassification to an extent that makes gesture-based interaction with the system a feasible alternative to traditional mouse/keyboard-interaction.

In our project, we will separate the notions of *gesture* and *posture*: We define a gesture as a movement or action consisting of a time-varying sequence of postures. A posture is defined as a specific

configuration of the input parameters: Hand position(s) and possibly the amount of finger curl.

Besides the gesture recognition functionality, the middleware should be able to proxy position, rotation and finger configuration data through to the application in the case of no gesture being recognised. This to accommodate functionality in the application such as controlling coordinate system rotation and grabbing objects.

Several important design decisions relate to this part of the software:

- Should the gestures be recognised continuously? This may lead to unintentional execution of commands defined by gestures and may be computationally expensive. Besides, it might incur a delay on data proxied through to the application if movements that are part of a gesture should not to be given to the application.
- Would it be advantageous to use a context sensitive gesture recogniser, e.g. one set of gestures recognised in "picking mode", another set in "coordinate system manipulation mode", etc.?
- What defines acceptable performance? This question is in part elaborated along with the evaluation criteria in the next section.
- How is 2D interaction handled? Is the user required to pick up a mouse, or may the gloves be used for 2D interaction (mouse emulation)?
- How does the application receive data from the middelware, and in what formats?

A sketch of the middleware layer is provided in figure 17.2. The rest of this chapter is devoted to exploring solutions for gesture recognition, as further investigation of the other aspects is more naturally done during the requrements specification.

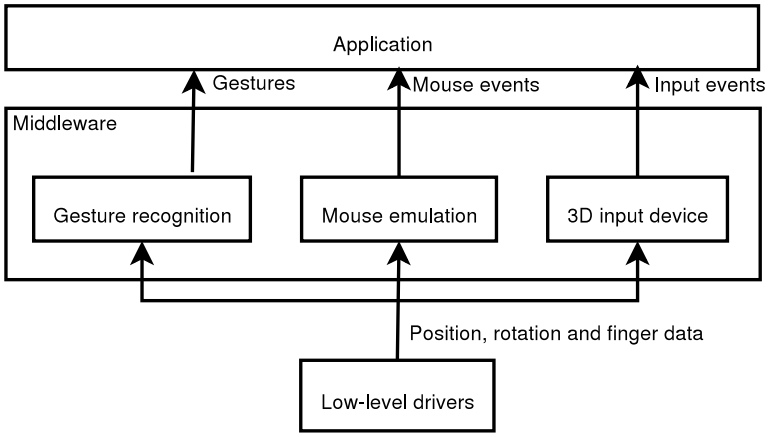

Figure 17.2: Middleware layer architecture

17.2.2 Evaluation criteria

There are several approaches to gesture recognition: Template-matching, dictionary lookup, statistical matching, linguistic matching, 3D finite state machines, neural networks and Hidden Markov

Models, in addition to ad-hoc methods ([JYYX94, FP04]). All these are faced with three different challenges:

- The learning problem: How are new gestures added to the system?
- The representation problem: How are gestures represented in a data-structure?
- The recognition problem: How are gestures recognised from input data?

Each approach to gesture recognition has different ways of solving these problems, resulting in different performance characteristics. When considering the methods, the following performance parameters are evaluated:

- How new gestures are introduced to the system. This can generally be achieved either by entering them manually in a formal gesture-specification language, or by example (training of the system). We consider the latter the most convenient from a usability point of view, if the number of required training samples is sufficiently small. The excact measure of "sufficiently small" is to be determined during the requirements specification phase.
- The computational complexity of the system. This is of particular importance since our system is required to be "on-line", recognising gestures in real time and providing feedback sufficiently fast for the user interface to feel responsive. Our measure for efficiency is to be decided upon during the requirements specification.
- Recognition rate. In order to be successful, the system must be able to recognise gestures correctly in most of the cases – that is, the user has to feel that the system is helping rather than hindering the work process. A measure for recognition rate is to be defined during the requirements specification. For trainable systems, this measure is a function of the size of the training set and is thus correlated to the maximum allowed number of examples needed to learn a gesture.
- Recognition mode. Whether the system is able to successfully recognise gestures performed continuously, possibly interleaved by random movements, or if it needs a signal at the beginning and the end of each gesture. Continuous recognition is believed to be harder and is obviously way more computationally expensive, since the algorithms for recognition have to be run on large amounts of data often not representing any gesture. In addition, this introduces the problem of not only choosing the most likely of gestures in response to a movement, but also determining (by a threshold or otherwise) if the action in question really was intended to constitute a gesture. There is also the aspect of the user unintentionally activating gestures in the case of a continuously running recogniser.
- Flexibility. Some approaches are directed specifically towards spatial-temporal recognition, making it difficult to accommodate finger position and movements in the recognition process.

In addition, documented examples of successful systems is considered to be favourable in the evaluation of an approach, as we believe that this reduces the amount of technological risk in the project.

17.2.3 Description of the different approaches

17.2.3.1 Template-matching

[Cox95] uses the following definition of template-matching:

> "Template matching is the classification of unknown samples by comparing them to known prototypes, or templates."

The templates are simply the raw data itself, a large volume of data compared to the input used by other methods. A large number of prototypes may thus make the use of template matching prohibitively expensive ([JYYX94]). Adding templates is done by example, and several templates may be averaged and used as a basis for calculation of expected variance.

Recognising a gesture in a database of templates is done by a classification of each template against some measure of match with the gesture data ([Cox95]). Since this extensive search would be computationally intensive, this method seems to be best suited when gestures are signalled by the user – a non-continuous system.

Template-matching systems are flexible in the sense that any number of inputs may be used as basis for the templates. The recognition rate depends on the chosen measure of match.

17.2.3.2 Dictionary lookup

When the data can be condensed to a small number of symbols, these may simply be looked up in a lookup-table, a dictionary (i.e. a hashtable). This is very efficient on recognition, but not very robust ([JYYX94]), as an exact match is needed (the "fuzziness" of the system resides in the sub-sampling into symbols).

Data entry may be done through examples, but trying to average several inputs will be meaningless, as it could lead to zero recognition even of the training set! Because of the lack of robustness, we will leave this method out of further consideration.

17.2.3.3 Statistical matching

Statistical matching methods derive classifiers from statistical properties of the training set. Some of these make assumptions about the distribution of the features, generating poor recognition performance when the assumptions are violated. Methods that don't make such assumptions tend to require huge amounts of example data to train, because they need to estimate the underlying distribution ([JYYX94]).

17.2.3.4 Linguistic matching

Linguistic matching makes use of state automata and formal grammar theory to recognise gestures. The problem is, however, that these grammars must be manually specified, thus making the system less adaptive ([JYYX94]). Because of this, the linguistic matching approach will not be considered further.

17.2.3.5 3D finite state machines

By using the test set to create geometrical volumes (ellipsoids, cylinders) defining the path followed in space (the volume representing variance from a piecewise linear path), gestures may be recognised by using state machines that change state when the positioning device moves through one piece of the piecewise linear path ([FP04]). This approach is both simple to implement and relatively cheap to run. Besides, training is simple and efficient. However, when the number of recorded gestures goes up, so does the number of misclassifications, because the volumes defining each gesture overlap increasingly.

This algorithm will in our system have to be augmented somewhat to accommodate finger curl.

17.2.3.6 Neural networks

A neural network is an interconnection of so-called Threshold Logic Units (TLUs) that calculates a sum of products between its binary inputs and a corresponding set of floating-point weights, comparing the sum to a threshold and emitting a 1 on the output if the sum exceeds the threshold. These networks are programmed by training, may be configured to map from any number of inputs to any number of outputs, and they may be used for continuous recognition. However, structuring these nets is still close to being a "black art", and running the nets is very expensive (especially in the training phase). Recognition rate is coupled tightly to the structure of the net. A great strength is flexibility, as one could easily add inputs for the fingers. Open-Source libraries exist (such as *Fann*).

Neural networks have a good record of applications to pattern-recognition and decision-making systems.

17.2.3.7 Hidden Markov Models

A Hidden Markov Model (HMM) is a doubly stochastic state machine operating on sequential strings of symbols in a finite alphabet. It is doubly stochastic in both defining state transitions and whether or not to emit an output symbol by probabilities. The models are applied by considering the input data as a series of observations and calculating the probability that each particular model may have given rise to that particular sequence of states (the actual state of the model is thus hidden, as one only has access to the observations).

These models are trained by example and store their data as matrices of probabilities. Recognition is

done by a form of heuristic search known as the *Viterbi algorithm*. They share many of the strengths of neural nets, such as great flexibility, trainability and ease of use. Open-Source libraries exist (such as *Torch*).

Hidden Markov Models seem to have become one of the most popular approaches to gesture recognition. For instance, [JYYX94], reports 99.78% recognition rate on a testing set of 450 samples in two dimensions. The system was also able to recognise gestures performed continuously. [FP04] recommends HMMs in the general case, even though 3D Finite State Machines gave a better result in his tests (see section 17.2.3.5 on 3D finite state machines). [JBM03] used HMMs (with the *Torch* library) for recognition of mono- and bi-manual gestures with good results, even though their hand tracking relied on cameras rather than position trackers. [LX96] created a HMM-based system that learned gestures incrementally, and that ran at acceptable speeds in an interpreted programming language.

17.2.3.8 Other approaches (ad-hoc solutions)

[FP04] proposes a simple solution using average vectors and finite state machines (FSMs) to represent gestures, recognising using least-distance classifications. This mechanism achieves good results with few samples in the training set, but is surpassed of the more advanced methods (3D FSMs, HMMs) when the training set size increases.

When it comes to finger-only gestures, this can be conveniently arranged with ad-hoc methods, for instance by using a threshold on finger curl value to identify whether a finger is curled or not and then define gestures as certain configurations of curled/not curled fingers.

17.2.4 Evaluation of the different approaches

To this point, six techniques remain for consideration. Table 17.6 shows a rough comparison between the different techniques.

Technique	**Complexity**	**Recognition rate**	**Continuous**	**Finger support**
Template-matching	High	Unknown	No	Yes
Statistical matching	Medium	Medium	Unknown	Yes
3D FSMs	Low	Medium	Unknown	No
Neural networks	High	High	Yes	Yes
HMMs	Medium	High	Yes	Yes
Vector FSM	Low	Low	Unknown	No

Table 17.6: Evaluation matrix for gesture recognition strategies

From the data presented in table 17.6, neural networks and Hidden Markov Models stand out as the best alternatives. In addition, these models can be combined, but we will not look into that possibility because of the complexity introduced by doing so. Given the number of references to successful gesture-recognition projects using HMMs, we choose this approach. See appendix F.1 for an elaboration of HMMs.

One point to mention, though, is that even for HMMs, there are several parameters to be tuned that can radically affect the performance of the system. We will as far as possible look at available research reports, but we cannot ignore the possibility that certain parameters must be decided by experiment or even intuition.

17.2.5 External library: Torch

We have found that a machine learning library, *Torch*, was packaged with Debian (we are required not to have any depencies outside the Debian "unstable" distribution). This is a C++-library that implements Hidden Markov Models, among other mechanisms for machine learning.

Torch is developed at *Dalle Molle Institute for Perceptual Artificial Intelligence* (IDIAP) in Switzerland, a semi-private research institution. It is used in [JBM03] for recognition of mono- and bi-manual gestures. We choose to have confidence in this library, as it seems to be actively maintained and extended, and it is developed at a serious research institution.

What is gained if adapting the library:

- A tested implementation of many important concepts.
- More time for other tasks, as one doesn't need to implement the machine learning functionality from scratch.
- Several methods for training: Expectation-Maximation (EM), the Viterbi algorithm, the Gradient-Descent algorithm.
- Several evaluation measures that may easily be interchanged makes it easier to by experiment find the optimal criteria for the training process.
- Routines for storing parameters and datasets in a disk file.
- The possibility to experiment with different distributions for the output probabilities and even different recognition machines (other than the HMM), though this will probably not be an issue in the first version of the product.

The downsides of choosing Torch:

- Dependence on an external library. We become dependent on that the development and maintenance of the library is continued over time, or the customer has to take over maintenance of the library.
- The need to learn the API of Torch. This has to be weighted against the effort of defining our own API, and it ought to be easier to learn Torch's API, as there are several tutorials and examples available, and the library has an API-documentation.
- The need to adapt the program to the library's interface. This means in particular the need for the gesture recogniser to (at least partly) be written in C++. [LX96] shows that gesture recognition can be done in interpreted languages such as Scheme, thus having to use C++ may possibly cancel out some of the time gained on not implementing the functionality ourselves (coding Python is believed to be faster than coding C++).

- If any special needs are discovered at a later time, one may need to extend or even modify the library's functionality, thus creating tighter coupling to the library and increasing the need for a thorough understanding of its workings.

17.3 The application layer

In this section we will evaluate possible solutions for the application layer of our end product. More specifically, what will be discussed is which graphics package to use in the demo application. Three different solutions will be evaluated, and the choice is provided in chapter 18.

17.3.1 Introduction

We need to use a graphics package for the application layer of our end product, since developing everything from scratch would be way too time consuming. Specifically, this consists of a demo application that shows the features of our library. Which package to use will be decided based upon the needs of our product, and we will also take into consideration which graphics package our customer uses in *SciCraft* today.

17.3.2 Evaluation criteria

In this section we will first discuss the needs of the demo application that leads to the evaluation criteria, and then list the criteria with our desired priorities/weights. Each evaluation criterion will be weighted from 1 to 5, where 1 is the lowest priority and 5 is the highest. The alternatives will be given grades from 1 to 5, where 1 is low, and 5 is high fulfillment of the criterion. These grades will be multiplied with its criterion's weight, and summed up for each alternative. This will give a basis for the choice of graphics package.

The graphics package will probably be used to render a molecule structure in the demo application and change it, based on the user's commands. Secondly, it will support graphical feedback to the user's commands, as well as a representation of the user's hand, probably a simple pyramid. Since we require only simple graphics primitives in our demo application, such as spheres, cylinders, boxes and cones, we choose not to consider this when deciding evaluation criteria. We simply require that each package we evaluate must support the basic 3D graphics primitives we have mentioned.

The customer have used *Visualisation Toolkit (VTK)* uptil now, and will most likely continue to use it in the future. Using the same package as SciCraft will make it easier for the *SciCraft* team to see how we have used the functionality in *Glisa*, and they can plug the graphical feedback almost directly into *SciCraft*. In addition, we might draw use of the experience the *SciCraft* team has with *Visualisation Toolkit (VTK)* if we are faced with programmatical problems or decisions.

Plugging in parts of our application level code into *SciCraft* is all the more easier if we use Python, as the *SciCraft* team have used. In addition, we have decided to use Python as much as we can, in order to achieve rapid development. Therefore we want the graphics package to have a Python

binding.

We generally want to use the most time on the middleware layer, since we believe this will take the longest time to complete. Therefore we want the graphical package to have a high conceptual level, since this often gives more rapid development, and less bug fixing.

The application level of our end product will be dependent on the graphics package, but we do not have to enclose the graphics package with our end product. So when it comes to licensing we are free to use a closed package.

This discussion leads to the criteria listed in table 17.7.

Criterion	**Weight**
Does the package have a Python binding?	5
Is the package already in use in *SciCraft* (VTK)?	3
Is the package on a high conceptual level?	4
Does the package have a good estimated overall quality?	4

Table 17.7: Evaluation criteria for the graphics package

17.3.3 Description of alternative solutions

In this section we will describe three different packages, namely *VTK*, *Open Inventor* and *PyMol*. The last one is not actually a graphics package, but rather an application for visualization of molecules, and was abandoned after a brief investigation.

17.3.3.1 Open Inventor

This section is based on information found on *Open Inventor*'s homepage [Gra03]. *Open Inventor* is an open source 3D graphics package from Silicon Graphics (SGI), as well as a standard file format for 3D graphics scenes. SGI is a renowned company, so we have faith in the quality of their product.

Open Inventor is built on top of OpenGL, which is a low level 3D rendering package, implemented in both hardware and software, and available at our customer's lab. It is implemented in C++ and SGI does not provide any Python bindings, as far as we can tell, but there exists Python bindings, like Pivy. Having to use an external Python binding adds more uncertainty compared to using a package that has built-in Python support.

Open Inventor is based on a 3D scene database and has an event model for 3D interaction. The scene graph consists of nodes, which can be geometrical primitives, such as cones, spheres, cubes and so on. It also has objects for camera, lights, a set of textures/materials and so on. We believe that developing in Open Inventor would not be too difficult, although it seems to be on a somewhat lower lever of abstraction compared to *VTK*, which we will describe next.

17.3.3.2 Visualization Toolkit

Visualisation Toolkit is an open source software system for computer 3D graphics, image processing and visualization. Its core consists of C++ classes, but has interfaces to languages like Java, Python and Tcl/Tk as well. It is independent of rendering devices, so it may be ported from system to system using the available rendering device. If ported to a system with a rendering device not supported by *VTK*, only the device-dependent classes must be written. It is also object-oriented, with each graphic actor in the scene represented as an object. This section is based on the technical paper [SML96] on *VTK* published on *VTK*'s homepage (http://www.vtk.org).

The object models *VTK* is designed upon the idea of two object models, the graphics model and the visualization model. The graphics model defines basic objects that together constitute a graphics scene. The visualization model is a dataflow model that defines different "stages" in the visualization pipeline.
The graphics model: The graphics model consists of the classes listed in table 17.8. To create a graphics scene, one must create instantiations of these classes and connect them to make a hierarchical representation of the scene.

Render master	The object controlling the scene and the rendering methods and creating the rendering windows
Render window	Represents a window in the windowing system and may be drawn in by multiple renderers
Renderer	Renders a graphics scene, consisting of actors, lights and camera
Light	Defines the lighting characteristics in a scene
Camera	Defines the camera characteristics, like angle and view/focal point
Actor	Defines an actual object in the graphics scene, constituted by the objects property(visual), a mapper(geometry), and a transform(position and orientation)
Property	Defines the visual attributes of an actor, ranging from texture, ambient, shading and more
Mapper	Defines the geometry of an actor, using a lookup table to map the object's datastructure to geometric primitives
Transform	Encapsulates a 4×4 transform matrix that can be altered through the methods of the class. Is used to define position and orientation of camera, actors and light

Table 17.8: The graphics model

The visualization model:
This model is made up of two basic object types: data objects and process objects. Process objects perform visualization algorithms on data objects, and data objects encapsulate the data needed, and methods for changing and accessing them. Process objects are one of three types, sources, filters and mappers. Sources encapsulate the data constructing a scene and yields an output dataset. These objects are at the start of the visualization pipeline. Filters require input data and yields output after having executed filter operations on the input data. Mappers are at the end of the pipeline and maps data to input for the rendering process.

17.3.3.3 PyMol

PyMol is a program for real time 3D visualization of molecules. It is open source, availible for *Debian* as a standard package, and is written in *C* and *Python*. Rendering is done with *OpenGL*, and support for stero viewing is present. Among the features are a built in command language for manipulating the view and selected objects in a scene. The rendering of molecules is generally of very high quality, and several different rendering methods are availible. The interface is also mature in the way manipulation of objects and navigation in a scene feels natural, and looks very impressive.

There are however a couple of reasons that made us abandon *PyMol* as an alternative. After using a couple of hours searching through APIs, user documentation and mailing lists, we could not find any easy way to interact directly with the 3D scene through commands without using a mouse. The other obstacle was that *Glisa* will need some form of graphical feedback of where the user has his/her hands in a 3D scene. This task could turn out to be very complicated in *PyMol* as we would have to modify the program itself, ie. we would not be able to only use the command interface of *PyMol*. Given the small amount of time availible for this project, it would not at all be feasible to integrate *PyMol* and *Glisa*, and we've therefore chosen not to do any further evaluation of *PyMol*.

17.3.4 Evaluation of the different alternatives

From the discussion above, we have made a comparison table of the remaining options, namely *Open Inventor* and *VTK*. The result is given in table 17.9

	VTK	Open Inventor
Does the package have a Python binding?	5	3
Is the package already in use in *SciCraft* (VTK)?	5	1
Is the package on a high conceptual level?	5	4
Does the package have a good estimated overall quality?	4	5

Table 17.9: Comparison of VTK and Open Inventor

Applying the weights of the evaluation criteria yields the result of the evaluation, given in table 17.10.

	VTK	Open Inventor
Does the package have a Python binding?	25	15
Is the package already in use in *SciCraft* (VTK)?	15	3
Is the package on a high conceptual level?	20	16
Does the package have a good estimated overall quality?	16	20
Sum	76	54

Table 17.10: Comparison of VTK and Open Inventor

From these table we see that *VTK* stands out as the best option. We will give our choice of graphics package in section 18, Conclusion.

17.4 Programming languages

It is a requirement from the customer that the code we produce is written in the C++ and/or Python programming languages. This chapter tries to give a brief introduction to the two languages with emphasis on shedding light on what tasks each language is best equipped to handle.

17.4.1 C++

C++ evolved from the C language, developed from the language B at Bell Laboratories in the years 1969-1973. The first C compiler was implemented on UNIX, which was developed at Bell at the same time. C++ was written in the years 1983-1985, and added support for object-orientation, templates, namespaces and Run-Time Type Identification (RTTI). [hit]

The C++ framework gives the programmer direct access to memory, and no run-time checks are performed. This is done to make the programs run as fast as possible, but the speedup comes at the cost that programs become harder to write and debug.

All valid C programs are per definition valid C++ programs. This means that C++ carry the consequences of many design decisions made in 1969, including functionality that often leads to unnecessary errors that are hard to find. Some of the more serious traps when writing a program in C++ are listed below:

- Arrays (and strings) are represented as the memory address, ϕ, of the first element. Accessing element n is simply accessing memory location $\phi + n$. It is the responsibility of the programmer that this location contains the data he or she wants to access – in the worst case, another variable is siletly touched making the program unreliable and seemingly indeterministic.

- Memory allocation/deallocation is the responsibility of the programmer, i.e. there is no garbage collection. Also, accessing deallocated memory yeilds no errors, but the results are undefined. Unfortunately, in many cases such accesses return the correct value, if no other part of the program has claimed the memory in question yet, introducing indeterminism in that adding code in one part of the program may break a totally different part.

- Newly created variables contain an undefined value. In practise, this means the last value assigned to the memory location where the variable is allocated. Using this value leads to indeterminism.

- The standard library (STL) for C++ is inherently unsafe, as there are no checks for errors, such as trying to iterate from start of list a to end of list b (which is meaningless). This can be countered by using *SafeSTL* during development.

All these types of errors can be discovered by using tools such as *Valgrind* (open-source for Linux) or Borland's *CodeGuard* for Windows. These are dynamic memory-debuggers that track memory accesses and allocation/deallocation, as well as access to uninitialised variables.

17.4.2 Python

Python.org ([Fou]) explains:

> "Python is a portable, interpreted, object-oriented programming language. Its development started in 1990 at CWI in Amsterdam, and continues under the ownership of the Python Software Foundation. The language has an elegant (but not over-simplified) syntax; a small number of powerful high-level data types are built in. Python can be extended in a systematic fashion by adding new modules implemented in a compiled language such as C or C++. Such extension modules can define new functions and variables as well as new object types."

The main reason for writing a program in Python, is the flexibility and development speed of a high-level language. Program fragments can be entered and tested in an interactive environment (the *Python shell*), and there is extensive cheking on data access, with exceptions thrown on error. Variables are dynamically typed, and functions may be used as values and are nestable (higher-order programming is possible).

17.4.3 Comparison

In our setting, we are very limited on time. This means that we must be able to develop the software rapidly. The time needed to write a program in Python is much shorter than the time for writing the corresponding program in C++, not only due to a more simplified language with more high-level operations, but also because bugs can be spotted earlier and ironed out more easily. Additionally, the project is of an exploratory nature, and the freedom to experiment through a flexible programming environment is favorable to the quality of the results.

The above arguments implies that as much of the code as possible should be written in Python. However, interfacing hardware through a C/C++ library is easier in C++, because even though one may generate Python bindings to the library, this must be done for each new version of the library, thus creating unecessary maintenance costs. In addition, an interpreted language will always run slower than a compiled one – also because of all the checks that are performed (that are unnecessary in a correct program) – and we may thus be forced to write some of the most computationally intensive code (such as pattern recognition of gestures) in C++. It might be a good idea, however, to code the intensive parts in Python first, converting the debugged code to C++ if it is too slow.

Chapter 18

Conclusion

In this prestudy we've described our customer's current situation and discovered several alternative ways to achieve our project goals. The following sections summarize the choices we have made, and why we have made them.

18.1 Low level drivers

When it comes to selecting which low level drivers, we can see from table 17.5, that drivers from manufactures acheives the highest score. We feel comfortable with this solution, as both *5DT* and *Ascencion-Tech(Flock of Birds)* seems like serious companies, and the drivers are well documented. Drivers from *Ascencion-Tech* must be tweaked, but the work will be considerably less complex than coding all from scratch.

18.2 Middleware solutions

Since this project primarily aims to support virtual gloves as input devices, functionality for providing the application with 3D input events is a requirement. When this is present, gesture recognition is desirable, and eventually the addition of mouse emulation will make most interaction tasks independent of the traditional input devices. The three parts of the middleware (see figure 18.1) are briefly described in the list below:

1. 3D input device: The gloves act as two separate input devices, reporting changes in position to the application.

2. Gesture recognition: When the middleware detects that a gesture has been performed, an event is sent to the application.

   We choose to implement the gesture recognition functionality using Hidden Markov Models, doubly stochastic state machines that can be trained to recognise sequences of information.

Initially, we aim to use a third-party library, *Torch*, to shorten development time and increase reliability.

3. Mouse emulation: The middleware may be set in a mode that provides mouse emulation, to enable interaction with conventional 2D elements of the underlying windowing system, such as dialog boxes. This functionality will not be prioritised to the same degree as the two other parts of the middleware.

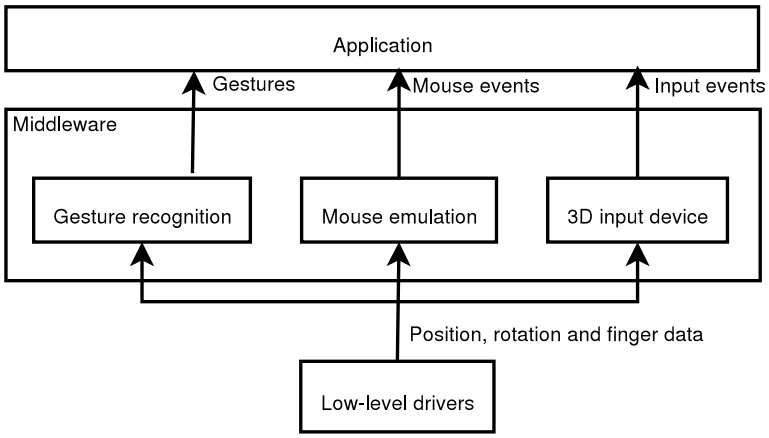

Figure 18.1: Middleware layer architecture (copy of figure 17.2)

18.3 Application layer solution

In the application layer we have considered which graphics package to use, and landed on Visualisation Toolkit (VTK), since we have found that it is a bit better than other options on many of the evaluation criteria. *VTK* was evaluated against *Open Inventor* and *PyMol*, but PyMol was found inappropriate and *Open Inventor* seems quite similar to *VTK*. An important premise for our conlusion was that *VTK* is the package that our customer is using and is likely to continue using in *SciCraft*. This may give some advantages like getting help from experienced *VTK* programmers and easier integration in *SciCraft*, as stated in chapter 17, Alternative solutions.

Part III

Requirements Specification

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Chapter 19

Introduction

This Software Requirements Specification (SRS) is based on the IEEE std 830-1998. Some chapters and/or sections of this standard are not applicable to this project and are therefore left out. These chapters are listed in section 19.3.

19.1 Purpose

The main purpose of the SRS is to accurately describe what the customer wants to achieve with the project. The creation of an SRS may help the customer realise vital requirements and help the software developers, in this case the project group's members, to understand the customer's needs. If the group members do not understand the needs, the final product may be of no use to the customer at all. The SRS will also function as a basis for the development of a test plan, and the existence of a complete SRS will simplify the process of testing whether or not the final product meets the customer's requirements. An SRS provides an agreement between the customer and the project group regarding the functionality of the end product.

The intended audience for the SRS are the tutors, the project group and the customer, Bjørn K. Alsberg at the Institute of Chemistry, NTNU.

19.2 Scope

This SRS describes the requirements of the software product *Glisa*, which product will be used in the VR lab at the Institute of Chemistry. *Glisa* will enable our customer to use virtual reality gloves when working with their application for multi-variate data analysis, *SciCraft*.

The overall objective of the project is to develop a library that can be used by the *SciCraft* software as an interface to the VR gloves. This will lead to the possibility of using the VR gloves as a more intuitive and user-friendly approach to manipulating data, which is especially meant to ease the handling and understanding of complex 3D-rendered molecules and to achieve a closer interaction

between analysis and visualisation.

Our product will:

- Support low-level communication with the virtual gloves and *Flock of Birds*.
- Let the gloves interact with 3D-objects in a VR environment.
- Feature a demonstration program that shows the functionality mentioned above.

19.3 Overview

The rest of this SRS will contain an overall description of our software product, *Glisa*, and its specific functional and non-functional requirements. The overall description gives a perspective of the system and how it fits in with its target environment. The requirements are divided into functional and non-functional requirements. In contrast to the IEEE std 830-1998, where all requirements are listed under a main chapter named *Specific requirements*, we have made two separate chapters for functional and non-functional requirements. The functional requirements describes the intended abilities of our end product. The non-functional requirements describes limitations, standards and target measurements.

With regards to the IEEE std 830-1998, we have decided not to include the following sections in the overall description chapter as they are considered irrelevant for our project:

- User interfaces
- Software interfaces
- Communications interfaces
- Memory constraints
- Operations
- Site adaption requirements

Additionally we have organised the chapter for specific requirements differently and included applicable parts as mentioned above.

An overall test plan has been worked out during the SRS phase. This is not part of the SRS document, but is in its own test plan document. The tests developed are a system test plan and a usability test plan.

Chapter 20

Overall description

This chapter describes the background for the requirements stated in chapter 3. It describes the conditions that affect the product and its requirements.

20.1 Product perspective

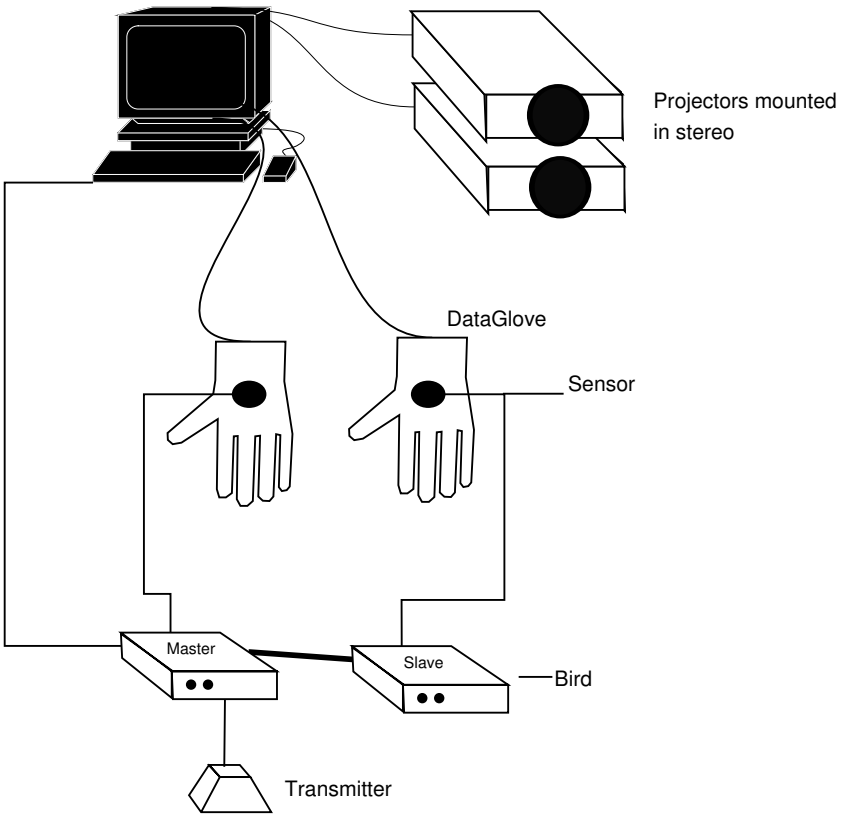

Figure 20.1: The setup of the computer and the other physical devices

Figure 20.1 displays how the virtual environment is set up. Two projectors are mounted in stereo and connected to the graphics card in the computer. A pair of gloves is connected to the computer

through serial to USB converters with a sensor is attached to each glove that is connected to a bird unit in the *Flock of Birds*. One bird is defined as master bird in the *Flock of birds*, and in addition to the sensor, a transmitter is also connected to this master. The master is connected to the computer through a serial interface.

Figure 20.2 shows how *Glisa* fits in with its environment. *Glisa* does all communication with the virtual gloves and *Flock of Birds*. A VTK application development team that wishes to use these HCI devices in their application, must use functions in *Glisa* to handle input, and displays graphics through the two projectors mounted in stereo.

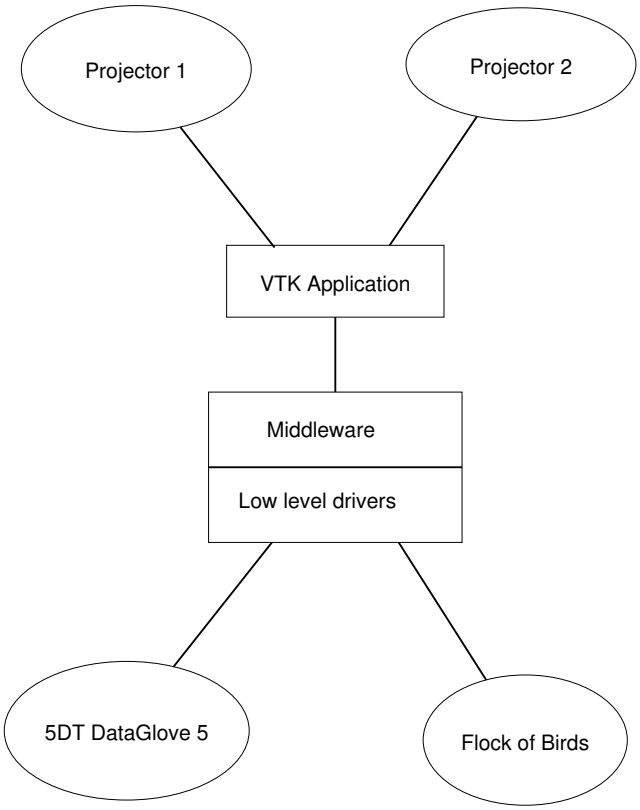

Figure 20.2: Overview of the parts of the system that work together

20.1.1 System interfaces

Glisa needs to have a clear-cut interface to the application level. That is, the calibration module, the gesture training module, the demo application and *SciCraft* will all have the same interface to *Glisa* through polling as well as events. The events *Glisa* must report to the application level are the following:

- 3D input events, consisting of:
  - Position coordinates.
  - Orientation coordinates.
  - 3D hand postures.

- Gesture events.

The requirements for the interface to *Glisa* are listed below:

- All events shall be similar to Qt mouse events, although they are not actually Qt mouse events.
- All events must have a time-stamp.
- Position and orientation data must be accessible by polling *Glisa*.
- Event handling shall be available in two modes, blocking and non-blocking. This is further explained under functional requirements in chapter 21.

20.1.2 Hardware interfaces

Glisa is supposed to interact with two main hardware components, namely the *5DT Data Gloves* and *Flock of Birds*. The *5DT Data Gloves* collect the amount of finger flexure on each finger, while the *Flock of Birds* collects position and orientation of the gloves. In this section we will describe the interfaces to these devices. We will support these two specific devices, but provide abstract modules so that one may use other VR gloves or positioning devices, as long as the device-specific code is rewritten.

20.1.2.1 Flock of Birds

The *Flock of Birds* is connected to the serial port on the customer's computer. We use a RS-232 interface and send commands in the form of characters for specifying the command type and integers for specifying addresses and other parameters. The transmission rate of the serial port (baud rate) of the serial port will have to be defined after experimentation.

20.1.2.2 5DT Data Gloves

The *5DT Data Gloves*, specifically *5DT Data Glove 5* also use serial interfaces, but are connected to the customer's computer to the Universal Serial Bus (USB) ports, via a converter from USB cable to regular serial cable. It is connected with two cables, one for each hand. The gloves use the RS-232 interface as well, and the baud rate must be set to 19200 bps.

20.2 Product functions

The major functions the software will perform are, as stated in the project charter:

- Communication between the existing system and the VR gloves and the motion tracking device.
  The software will enable communication between *SciCraft* and VR gloves and the motion tracking device.
- Showing the virtual gloves' functionality.
  The software will show the possibilities and limitations in the functionality of the VR gloves in a demo application.
- Allow the VR gloves to interact with 3D-objects in a VR environment.
  The software will provide an interface to the VR gloves, so that *SciCraft* may use them as a 3d input device.

These functions will assist in accomplishing the following overall goals:

- Reduce the need to use the keyboard in work tasks.
  The software will make the primary instructions from the user to the computer keyboard-independent.
- Making the use of *SciCraft* more intuitive.
  The software will make tasks in *SciCraft*, like molecule building and other complex tasks in a 3D environment, easier and more intuitive.
- Achieve a closer interaction between analysis and visualisation.
  The software will support a closer interaction between analysis and visualisation when *SciCraft* is used for data analysis. *SciCraft* may use our product to support for example intuitive manipulation of analysis parameters and let the user see the effects instantly.

20.3 User characteristics

There are two different groups of users related to the end product of this project. These are described in the list below.

- The first group consists of the users of the complete system the end product of the project is to become a part of, namely *SciCraft*. The intended user of this system is a person educated within the field of chemistry. His/her experience with systems similar to *Glisa* is negligible. The user will have experience in using tools for data analysis, but the VR-approach to this will be unknown. The user's expertise in computer science is considered to be at the level of running applications.
- The second group consists of the programmers whose task is to integrate the end product of this project with the existing system, *SciCraft*. The *SciCraft* developers are educated within the field of computer science, and are highly experienced with systems similar to the end product.

Chapter 21

Functional requirements

This chapter presents the defined functional requirements of the project *Glisa*. The functional requirements are split into three main parts: application specific, support application specific, and middleware specific requirements. These three groups of requirements are highly related, but represent different levels of abstraction. The application specific requirements are mainly targeted at user group one described in section 20.3, whereas the middleware specific requirements are mainly targeted at user group two in the described in the same section. The reason for separating the support applications specific requirement from the application specific requirements is that two separate applications for calibration and gesture training are needed.

The application specific requirements are listed in table 21.2, the support applications specific requirements are listed in table 21.1, while the middleware specific requirements are listed in table 21.3 and each requirement is given a priority on the scale; high, medium and low. High priority requirements are essential to the customer and must be fulfilled. Low priority requirements are optional and implemented if there is sufficient time. Medium priority requirements are not optional, but if serious problems arise, these are ranked as less important than the high priority ones and if they are not implemented the process of implementing them in the future should be well documented. These requirements are grouped after functionality rather than priority, and they are further elaborated in section 21.1 to 21.3.

The project group uses time boxing during the implementation of the requirements. Different requirements are to be implemented during different time boxes. High priority requirements will be scheduled in early time boxes, while medium and low priority requirements will be scheduled in later time boxes. A requirement not implemented in its intended time box will be moved to the following time box, resulting in that possible requirements not met at the end of the implementation phase will be the requirements with the lowest priority, thus ensuring fulfilling high priority requirements.

ID	**Requirement**	**Priority**
SA-1	The application shall facilitate training of new gestures and add them to the system	Low
SA-2	The system shall be able to calibrate the 3D environment with regards to mapping of real 3D space versus projected 3D space.	High

Table 21.1: Specific requirements for support applications

Specified hand movements for each requirement is illustrated and described in section 21.1.

ID	Requirement	Priority
A-1	The application shall provide a method for changing from 3D input mode to 2D mouse emulation mode.	Medium
A-2	The application shall provide a method for changing from 2D mouse emulation mode to 3D input mode.	Medium
A-3	In 2D mouse emulation mode the user shall be able to use the hand to emulate left clicking on the mouse.	Medium
A-4	In 2D mouse emulation mode the user shall be able to use the hand to emulate right clicking on the mouse.	Medium
A-5	In 2D mouse emulation mode the user shall be able to use the hand to move the mouse pointer.	Medium
A-6	The application shall recognise performed gestures.	Medium
A-7	The application shall track the movement of both gloves and provide a graphical representation of the pointers.	High
A-8	The application shall be able to detect selection of an object in the 3D space.	High
A-9	The application shall facilitate the selection of several objects in 3D mode by marking an area.	Medium
A-10	The application shall enable grabbing and releasing of objects.	Medium
A-11	The application shall enable movement and rotation of grabbed objects.	High
A-12	The system shall facilitate navigation through the 3D space	High

Table 21.2: Application specific requirements

ID	Requirement	Priority
M-1	The system shall run in a continuous loop, polling for and distributing events to the application.	High
M-2	The system shall collect events and release them to the application upon request.	Medium
M-3	The gesture recognition system shall be programmed by training.	Medium
M-4	The gesture recognition system shall be able to recognise certain sequences of actions as previously trained gestures and report this to the application.	Medium
M-5	The gesture recognition system shall be able to identify a set of default gestures	Low
M-6	The gesture recognition system shall enable the application to subscribe gesture events, and enable and disable recognition of individual gestures.	High
M-7	The system shall report three dimensional input data for glove position and rotation to the subscribing software entities when it is in *3D input device* mode.	High
M-8	The system shall recognise grab and release events and notify subscribing software entities when these are performed.	Medium
M-9	The system shall be able to report finger flexure in the range [0.0, 1.0] upon request from the application.	High
M-10	The system shall report events of the type; mouse move, mouse button down and mouse button up to the operating system when in *Mouse emulation mode*.	Medium
M-11	The system shall always show in which mode it is operating.	Low
M-12	The system shall be able to establish a mapping between physical and virtual space.	High

Table 21.3: Middleware specific requirements

21.1 Application specific functional requirements

The application part of *Glisa* shall demonstrate the functionality and possibilities of a system using virtual reality gloves. Support applications for 3D calibration and gesture training are also needed. This section specifies the requirements necessary to do this.

21.1.0.3 Different modes of operation

Glisa is meant to be used in a 3D environment that appears inside a normal application. The normal application will include buttons and menus that are not displayed in 3D. Since it would be inconvenient to use a combination of the mouse/keyboard and the virtual glove, *Glisa* must have a way to operate the 2D functions of the program with the gloves. The way we have chosen to do this, is to have two modes of operations for the gloves: In 3D input mode the gloves act as pointing devices in the three dimensional space. In 2D mouse emulation mode, the gloves control the movement and actions of the mouse in the 2D part of the program. In addition to these two modes, we have defined a mode for performing gestures. The gestures are special hand movements that can be performed when in 3D mode to execute functions in the program.

21.1.0.4 Transition from 3D mode to 2D mode

The application must support a method for changing from 3D input mode to 2D mouse emulation mode. The posture for performing this is shown in figure 21.1.

ID	A-1
Inputs	The user performs a posture with the index and middle fingers extended, and the other fingers flexed. The posture can be done with any hand, in any position and at any angle.
Processing	The 2D mouse pointer is moved to a position projected from the hand that performed the posture to the screen.
Outputs	The application is set to 2D input mode, with the hand that performed the posture used as a mouse emulator.

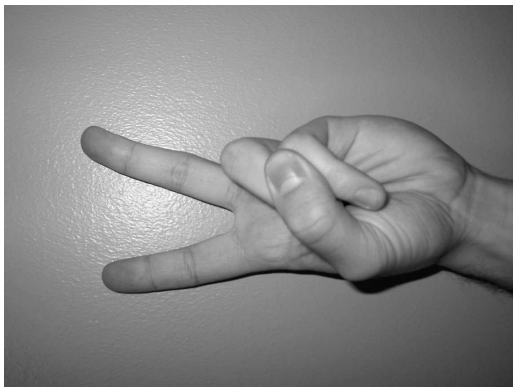

Figure 21.1: The posture for switching from 3D mode to 2D mode as described in requirement A-1

21.1.0.5 Transition from 2D mode to 3D mode

The application must support a method for changing from 2D mouse emulation mode to 3D input mode. The posture for performing this is shown in figure 21.2.

ID	A-2
Inputs	The user performs a posture with the thumb, index and middle fingers extended, and the other fingers flexed. The posture can be done with any hand, in any position and at any angle.
Processing	The 3D pointer indicators are moved to positions corresponding to the position of the hands when the posture is performed.
Outputs	The application is set to 3D input mode.

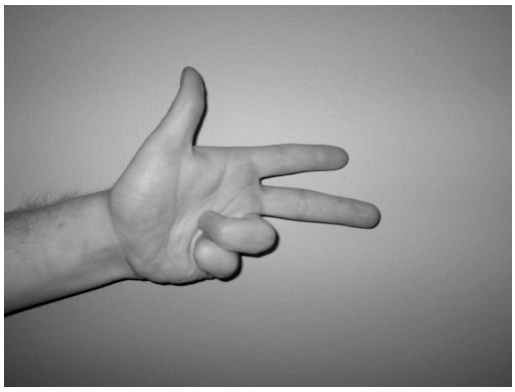

Figure 21.2: The posture for switching from 2D mode to 3D mode as described in requirement A-2

21.1.0.6 Left clicking the emulated mouse

In 2D mouse emulation mode the user must be able to use the hand to emulate left clicking on the mouse. Double clicking is performed by doing the left clicking twice in rapid succession. Drag and drop functionality is enabled by pressing the mouse button and moving the mouse before releasing the button again. The postures for performing this are shown in figure 21.3 and figure 21.4.

ID	A-3
Inputs	The user clicks the left mouse button on the emulated mouse by flexing and extending the index finger. The user starts the left clicking with the index finger extended, then flexes it as an emulation to pressing the left mouse button. Extending the index finger again emulates releasing the left mouse button.
Processing	The system must retrieve the position of the hand that emulates the mouse, and simulate a mouse action in the windowing system.
Outputs	The windowing system is informed on where and how the user performs the emulated mouse actions.

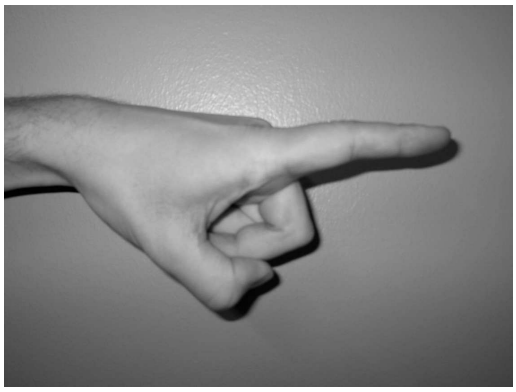

Figure 21.3: Extended index finger in the posture left clicking as described in requirement A-3

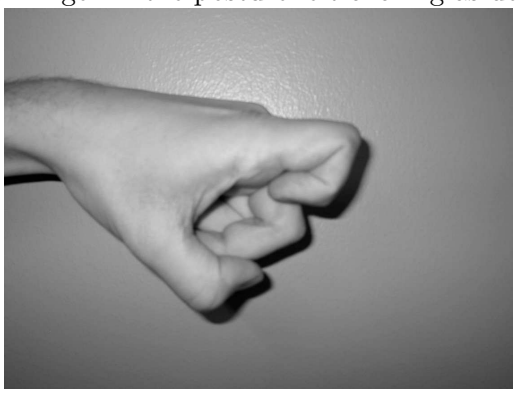

Figure 21.4: Flexed index finger in the posture for left clicking as described in requirement A-3

21.1.0.7 Right clicking the emulated mouse

In 2D mouse emulation mode the user must be able to use the hand to emulate right clicking on the mouse. The postures for performing this is shown in figure 21.5 and figure 21.6.

ID	A-4
Inputs	The user clicks the right mouse button on the emulated mouse by flexing and extending the thumb on the hand the emulates the mouse.
Processing	The system must retrieve the position of the hand that emulates the mouse, and simulate a mouse action in the windowing system.
Outputs	The windowing system is informed on where and how the user performs the emulated mouse actions.

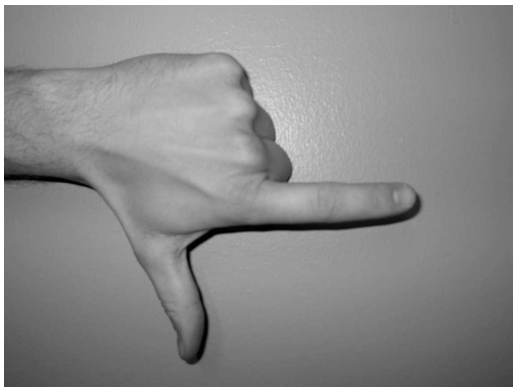

Figure 21.5: Extended thumb in the posture right clicking as described in requirement A-4

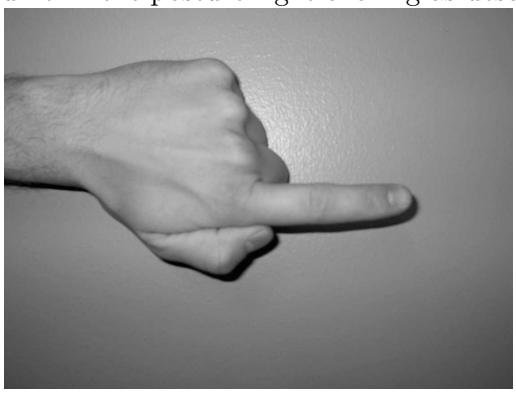

Figure 21.6: Flexed thumb in the posture for right clicking as described in requirement A-4

21.1.0.8 Moving the mouse pointer in 2D mode

When the system is in 2D mouse emulation mode, the index finger on the hand that marked the transition from 3D mode to 2D mode controls the movement of the mouse pointer.

ID	A-5
Inputs	Movement of the hand emulating the 2D mouse.
Processing	The system must project the movement i 3D space to coordinates in 2D.
Outputs	The mouse pointer moves to the position desired by the user.

21.1.0.9 Gestures

A gesture is a movement of a hand in a predetermined pattern. The application must be able to recognise when the user performs such gestures. Two gestures can be performed simultaneously, one with each hand. The posture for signalling gestures is shown in figure 21.7

ID	A-6
Inputs	The user extends the thumb and flexes all other fingers on the hand. While keeping this hand posture, the user moves the hand along a predetermined pattern. The gesture can be performed with any of the hands, but must be performed in the same way as they were defined, i.e. mirroring of gestures is not performed.
Processing	The system must recognise the gesture and determine which function to trigger.
Outputs	The expected action is taken by the program. It must be visualised graphically.

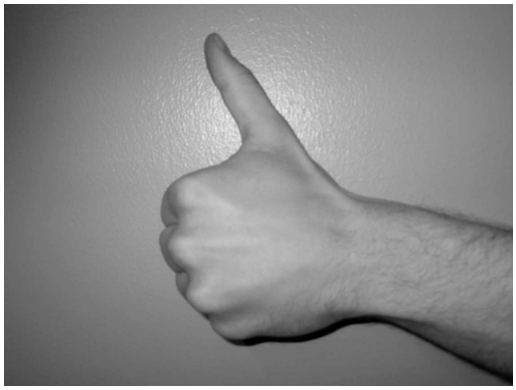

Figure 21.7: Posture for doing a gesture as described in requirement A-6

21.1.0.10 The hands as 3D input devices

When in 3D mode, both hands are used as input devices. The application must track their movement in 3D space and provide a graphical representation of the pointers.

ID	A-7
Inputs	Positions of both hands.
Processing	The system maps the position of the hands to the position of the pointers in the 3D space.
Outputs	Each pointer is visualised by a pyramid showing position, roll, pitch and yaw of the pointer. If a hand is moved outside the area that maps into the 3D space, the pointer belonging to that hand, stops at the edge of the space and tracks to the position closest to the hand.

21.1.0.11 Selection of an object in 3D mode

The application must be able to detect selection of an object in the 3D space. Two different postures for carrying out this selection are shown in figure 21.8 and figure 21.9.

ID	A-8
Inputs	The system must track the coordinates of the hands as input to where the 3D pointer indicator is located. If the index finger is partially flexed and the thumb extended, the system perceives the posture as a selection. How much the index finger must be flexed, must be defined at a later stage after experimentation.
Processing	The system uses the coordinates of the hand to calculate the probable position of the tip of the pointing device. The closest object to the tip of the pointer indicator when the selection posture is performed, must be selected. A limit on how far away the object can be in order to be selected, must be found during the implementation and testing of this requirement.
Outputs	The program must visualise the selection of the object.

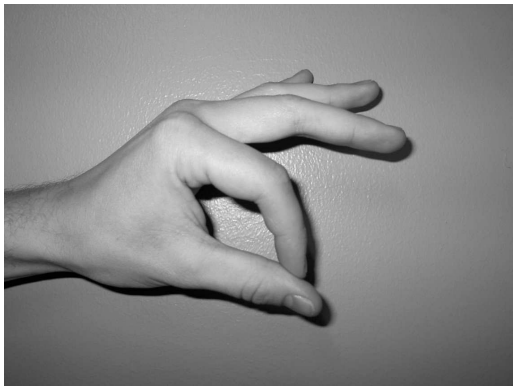

Figure 21.8: One posture for doing a selection as described in requirement A-8

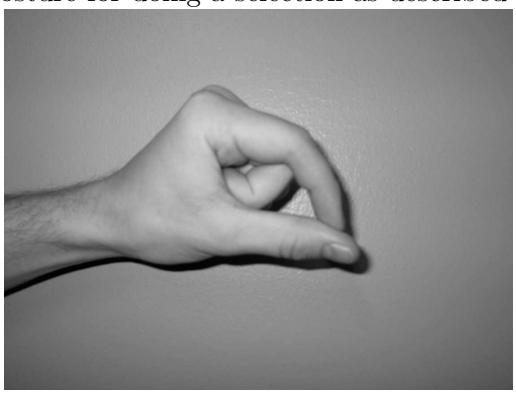

Figure 21.9: Another posture for doing a selection as described in requirement A-8

21.1.0.12 Selection of objects in 3D mode by selecting a volume

The application shall facilitate marking objects in a 3D environment. This is an extended version of selecting a single object, making it possible to select several objects simultaneously and perform actions on them as a group. The sequence of postures for obtaining this functionality are shown in figure 21.10, figure 21.11 and figure 21.12.

ID	A-9
Inputs	Two opposite corners of a box is represented by the two index fingers extended. The action is started by connecting the fingertips of both index fingers. The box is expanded when the index fingers are moved apart. When the index fingers are flexed, the box size is set. The input to the system is the coordinates that span the selection box.
Processing	The system must calculate the box continuously to track the movement of the fingers. When the box is placed, the system must decide which objects are within the marked space.
Outputs	The box is visualised continuously. After the box is placed, the selection of objects must also be visualised.

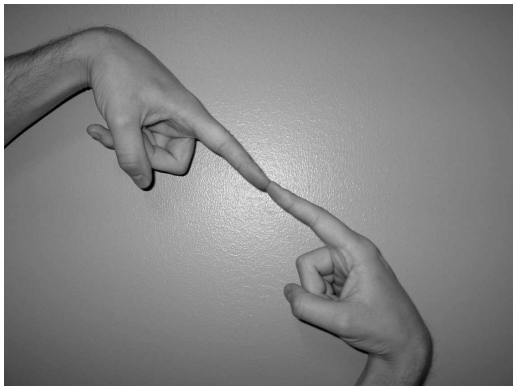

Figure 21.10: Connected index fingers as described in requirement A-9

Figure 21.11: Index fingers moving apart as described in requirement A-9

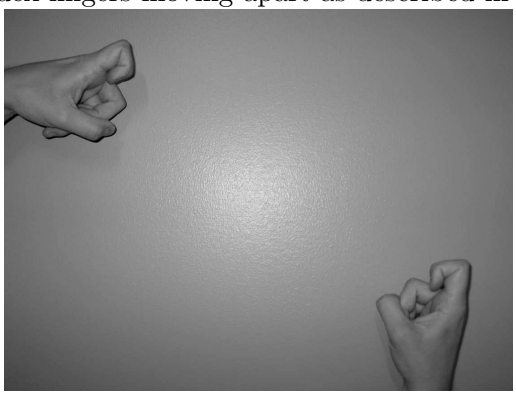

Figure 21.12: Posture for setting the box size final as described in requirement A-9

21.1.0.13 Grabbing and releasing objects in 3D mode

Grabbing objects enables the possibility to move and/or rotate objects. The system must support this functionality. After the user has done the desired translations and/or rotations on an object, the system must support releasing of objects. The postures grabbing and releasing objects are shown in figure 21.13 and figure 21.14.

ID	A-10
Inputs	Grabbing is done by flexing all fingers when the pointer indicator touches an object. Releasing the objects is performed by extending the fingers again.
Processing	The system must decide which object that is to be set as grabbed/released. The system must also keep track of an internal state of whether any objects are grabbed or released.
Outputs	The system must visualise the grabbing and releasing of an object.

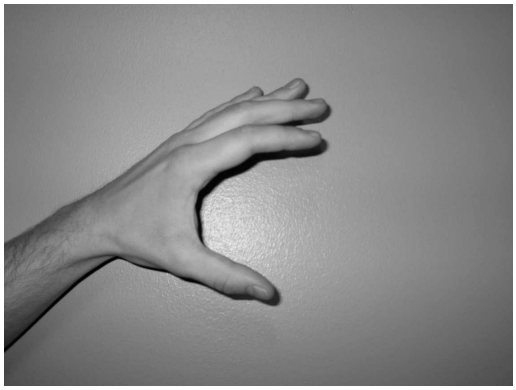

Figure 21.13: Posture for releasing as described in requirement A-10

Figure 21.14: Posture for grabbing as described in requirement A-10

21.1.0.14 Moving and rotating objects

When an object is grabbed in 3D mode, it can be moved or rotated.

ID	A-11
Inputs	The input to the system is the coordinates of the hand that is grabbing the object.
Processing	The system translates and/or rotates the object according to the user input.
Outputs	The system must continuously show the changes when an object is moved and/or rotated.

21.1.0.15 Navigation in 3D space

Navigation in 3D space facilitates navigating through 3D objects. The system shall support this functionality.

ID	A-12
Inputs	All the fingers of one of the hands are extended. When moving the hand along the x, y and z axes, the coordinate system should move accordingly.
Processing	The system must keep track of the coordinates of the navigating hand and move the coordinate system accordingly.
Outputs	The system must continuously show changes in the coordinate system, reflecting the hand movements.

21.2 Support application specific requirements

In addition to the application specified above, two stand-alone applications are needed. One for training of gestures and one for calibration.

21.2.1 Training of gestures

The application shall demonstrate how new gestures can be added and trained.

ID	SA-1
Inputs	Input to the system shall be a training set of examples of gestures, a gesture repeated a number of times. An action to be performed with the gesture is also to be specified.
Processing	The system must be able to recognise gestures and map different gestures to different actions.
Outputs	The system must visualise that a gesture is performed and execute a specified action.

21.2.2 Calibrating the 3D environment

The system must support calibration of the 3D environment. This calibration is a mapping of the real 3D space to the 3D space projected in the application.

ID	SA-2
Inputs	8 balls will be presented to the user. The user must the point at the balls in a predefined order. The inputs to the system are the coordinates at which the user are pointing.
Processing	The system must map the real 3D space to the virtual 3D space, using the coordinates given by the user.
Outputs	The system will be in a calibrated state.

21.3 Middleware specific requirements

This section elaborates the specific requirements for the middleware layer of the library.

The middleware constitutes the interface between the application and *Glisa*. Communication across this interface is based on events that the application signs up to receive, and that are transmitted as calls to callback functions in object-oriented interfaces. Several software entities in the application may sign up for the same event type. In addition to the event-based interface, the application may at any time request the same information from *Glisa*, i.e. polling.

21.3.1 Mode of operation

It is a requirement that *Glisa* may be run in two different modes: blocking and non-blocking. These two modes will support both single- and multithreaded applications.

21.3.1.1 Blocking mode

The system shall run in a loop continuously polling the hardware and distributing events to the application.

ID	M-1
Inputs	All inputs from the low-level drivers.
Processing	The system continuously collects data from the low-level drivers, translates this data into events and distributes the events to the subscribing software entities.
Outputs	Events to all subscribing software entities.

21.3.1.2 Non-blocking mode

The system shall collect events and release them to the application upon request.

ID	M-2
Inputs	• Request for events from the application. • All inputs from the low-level drivers.
Processing	All pending inputs from the low-level drivers are translated to events and distributed to all subscribing software entities.
Outputs	Events to all subscribing software entities.

21.3.2 Gesture recogniser

Glisa is meant to enable users to control an interactive application by using VR gloves, and by this avoiding conventional mouse/keyboard interaction. In acheiving this goal, the use of hand gestures to issue commands is essential, and this section describes the specific requirements for the gesture recognition functionality.

21.3.2.1 Gesture learning

The gesture recognition system shall be programmed by training.

Gesture recognition will be performed by machine learning strategies, as stated in the pre-study document. These models must be trained with representative samples of gestures.

ID	M-3
Inputs	• A set of gesture samples in the form of sequences of input data. • Which of the gloves that was/were used for recording the example data. This can be either the left or the right glove.
Processing	Learning of gestures is performed by applying a training algorithm to the machine-learning framework. For details, see appendix F.1.
Outputs	The gesture learning procedure returns an identifier for the newly created gesture. Configuration data acheived from the training algorithm is stored in a gesture repository on permanent storage. In the case of an I/O error or an abnormal condition in the training algorithm (such as that no convergence could be acheived), an error is signalled and no changes persist in the library's internal state.

21.3.2.2 Gesture recognition

The gesture recognition system shall be able to recognise certain sequences of actions as previously trained gestures and report this to the application. Gesture recognition is performed by the machine learning framework, and when a gesture is identified, this is signalled to the application.

Before data is presented to the gesture recongniser, it is segmented into gesture candidates by determining when all fingers except the thumb are flexed and the hand is moving (see figure 21.7). This process gives out sequences of information that may be recognised by the machine learning strategies employed.

ID	M-4
Inputs	• A sequence of positional data from one glove.
Processing	Gesture recognition is done by running a recognition algorithm on the machine learning framework. This is explained in the pre-study document.
Outputs	When a gesture is recognised, the gesture recogniser sends an event to the software entities registered for the particular type of gesture recognised. If a sequence of input data cannot be identified as a gesture, the module handling the graphical feedback is alerted to give the application an opportunity to present the fact that the attempt to give a command failed.

21.3.2.3 Default (built-in) gestures

The gesture recognition system shall be able to identify a set of default gestures

The set of bulit-in gestures are the ones described in fig 21.15 - 21.18. The figures show the patterns in which to move the hand.

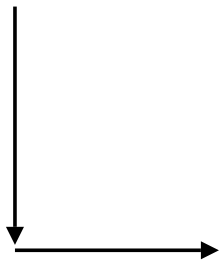

Figure 21.15: Built-in gesture as described in requirement M-5

To demonstrate the ability of the system to recognise gestures, and to provide gestures for common operations, a number of pre-defined gestures are trained and delivered with the system. These gestures will not be mapped to any default actions, but it shall be possible for the user to map them to user-defined actions.

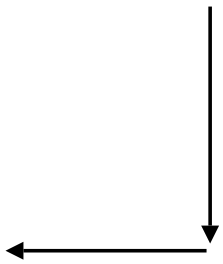

Figure 21.16: Built-in gesture as described in requirement M-5

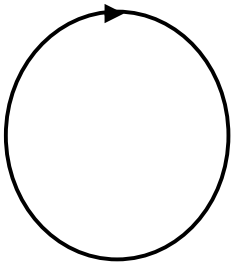

Figure 21.17: Built-in gesture as described in requirement M-5

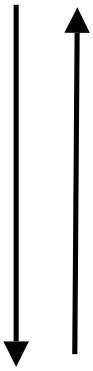

Figure 21.18: Built-in gesture as described in requirement M-5

ID	M-5
Inputs	One of the pre-defined gestures is performed.
Processing	The recognition procedure processes the input data.
Outputs	The system responds with the generation of an event of the correct type, if the gesture in question is enabled.

21.3.2.4 Gesture activation and deactivation

The gesture recognition system shall enable the application to subscribe gesture events, and enable and disable recognition of individual gestures.

ID	M-6
Inputs	• A gesture identifier or identification of a set of gestures. • A reference to the software entity that is to be informed about that the gesture has been executed. To deactivate a gesture, the gesture identifier is sufficient as input.
Processing	When a gesture is activated, it is associated with the reference to the software entitity to be alerted and the machine learning setup is changed accordingly. Upon deactivation of a gesture, the association to a software entity is deleted and the a corresponding update done in the machine learning setup.
Outputs	If the gesture identifier is invalid, an error is signalled and no actions are performed (the internal state of the middleware remains unaltered).

21.3.3 3D Input device and Mouse Emulation

Glisa may operate in one of two different modes when it comes to using the gloves as input devices (apart from recognising gestures):

- 3D Input Device – In this mode, the gloves report their position and orientation in three dimensional space, in addition to finger postures.
- Mouse Emulation – In this mode, one glove moves the window system's mouse pointer and may issue click or drag events.

Within the application using *Glisa*, any number of software entities may be subscribing 2D and/or 3D input events. When the system is in one particular mode, events from the other mode are not produced. Values for the applicable parameters may in 3D mode also be retrieved through polling.

21.3.3.1 Position and orientation updates in 3D input device mode

The system shall report the following types of three dimensional input data to the subscribing software entities when it is in *3D input device* mode:

- Position in three dimensional cartesian object space. Whenever the position of a glove is changed, the new position is reported to the subscribing software entities. These coordinates are to be given in the application's own reference system (transformed by the transformation calculated from the calibration procedure).
- Rotation around the three principal axes. Whenever the orientation of a glove is changed, the new rotation angles are reported to the subscribing software entities. The angles to be reported are: Rotation around X axis, rotation around Y axis and rotation around Z axis.

Reporting of events to the application is done whenever the position or orientation of a glove is changed.

ID	M-7
Inputs	The following input data is needed whenever a glove has been moved or tilted: • Position data (x, y and z) in the reference frame of the positioning device. • Rotation around the three principal axes (X, Y and Z). • Calibration data.
Processing	Positional data is multiplied with the transformation matrix obtained from the calibration procedure.
Outputs	Rotation angles and transformed positional data are passed to the software entities that are subscribing 3D input events if the system is in *3D Input Device* mode.

21.3.3.2 Grabbing events in 3D input device mode

When manipulating a virtual environment, it is essential to have the ability to grab objects and move them around. The system shall recognise grab and release events and notify subscribing software entities when these are performed.

ID	M-8
Inputs	Finger flexure information from the low-level drivers.
Processing	Finger flexure is monitored to detect when all fingers are flexed past a given threshold (set as a configuration property).
Outputs	An event is emitted to the application when a grab or release is detected.

21.3.3.3 Finger flexure measurements in 3D input mode

For specific purposes, an application might want access to the exact measures of finger curl. The system shall be able to report finger flexure in the range [0.0, 1.0] upon request from the application.

ID	M-9
Inputs	• Request from the application. • Finger flexure data.
Processing	Data aquired from the harware is normalised to [0,1] by the transformation $d_i = \frac{D_i}{D_{\max}}$ for each component D_i, where $D_{\max}$ denotes the maximum value of parameters D.
Outputs	Normalised finger flexure information is output.

21.3.3.4 Input events in mouse emulation mode

When interacting with the interface of the windowing system, three dimensional input is not supported. Much of the required interaction may be done using a computer mouse, but picking up a

mouse is inconvenient in the setting of using virtual gloves for controlling the computer. Therefore, it is desirable to be able to issue mouse commands using the gloves.

The system shall report the following types of events to the operating system when in *Mouse Emulation* mode:

- Mouse move. The glove active for mouse emulation has moved.
- Mouse button down. The action for mouse down has been performed by the user. This applies to both (left, right) mouse buttons.
- Mouse button up. The action for mouse up has been performed by the user. This applies to both (left, right) mouse buttons.

ID	M-10
Inputs	• Position of the glove enabled for mouse emulation in the application's reference frame. • Finger flexure information. • Calibration data.
Processing	From the coordinates of the glove, the mouse pointer's position is calculated as the projection of the index fingertip onto the screen-plane. Updates in the glove's position are reflected as mouse movement events. When the fingers are flexed into the postures described with the application requirements for mouse buttons (see requirements A-3 and A-4), mouse click events are generated.
Outputs	Events of the types mentioned above are sent to the operating system if the system is in *Mouse Emulation* mode.

21.3.4 Feedback

Since the gloves that are to be used with *Glisa* are not equipped with tactile feedback (enabling the user to feel the objects in the virtual surroundings), and since the objects to be manipulated can be perceived to be at a certain distance, a feedback on the exact position and orientation of the gloves is desirable. Because this requires interaction with the graphics system used, the application using *Glisa* must responsible for drawing the feedback.

Positional feedback is derived from the pointer positions in *3D input device mode*, while status feedback must be signalled separately, so that the application can visualise the state of the library. Also, the system needs to display objects to be touched during calibration to be able to map between the physical and virtual environments.

21.3.4.1 Feedback on operation mode

When dealing with a modal system where one command may have different meanings depending on the current mode, it is paramount that the user is aware of what mode the system currently is in to issue the correct command to acheive the desired effects.

The system shall always show in which mode it is operating.

ID	M-11
Inputs	• Current mode of operation.
Processing	No processing other than a request.
Outputs	Indication of the current mode.

21.3.4.2 Calibration

The application operates on objects in a virtual 3D space, while the gloves are positioned in the physical world, relative to a positioning device's transmitter. If glove input is to be useful for the application, the physical coordinates for the gloves need to be converted to virtual coordinates, and to acheive this, a mapping function has to be established by a calibration procedure.

The system shall be able to establish a mapping between physical and virtual space.

ID	M-12
Inputs	• Spatial positions for different known positions in object virtual space.
Processing	A regression analysis is performed on the set of physical and virtual coordinate pairs in addition the current viewing parameters to calculate a mapping between coordinates in
Outputs	*Glisa* is in a state where physical coordinates are transformed correctly to coordinates within a unit cube (all coordinate components are in the range $[-1, 1]$).

Chapter 22

Non-functional requirements

This section describes the non-functional requirements of *Glisa*. These requirements will be grouped according to the IEEE-830 and ordered by decreasing priority.

22.1 Performance characteristics

These requirements relate to how well the product meet the functional requirements in measurable terms; how fast, how many and so on. The requirements are listed in table 22.1.

ID	Requirement	Priority
NFP-1	Gestures shall have a recognition rate of at least 80% when only the built-in gestures are defined. When many more gestures are defined the recognition rate may be lower.	High
NFP-2	The application must be able to trace the position and orientation of the gloves at a rate of 60 Hz, i.e. being able to display up to 60 different positions and orientations per second.	Medium
NFP-3	The accuracy of the pointing device is defined as adequate if at least 70% of the test persons approve of the accuracy in the usability test.	Medium
NFP-4	Recognising of an arbitrary gesture shall take no more than 0.1 seconds.	Medium
NFP-5	The deviation of the synchronisation between *Flock of birds* and the VR gloves should be less than 1/30second.	Medium
NFP-6	The gesture recogniser shall not need more than 40 examples of a gesture in the training set when training the built-in gestures. The training set may have to be larger when many more gestures are defined.	Low

Table 22.1: Performance characteristics

22.2 Design constraints

This requirement put restrictions on our design of *Glisa*, and is listed in table 22.2.

ID	Requirement	Priority
NFDC-1	All drivers in this module shall be independent of VTK. This is required so that the customer may later switch to another visualisation environment.	High

Table 22.2: Design constraints

22.3 Maintainability

These requirements relate to future maintenance of the system. Fulfilling these requirements will ease maintenance for the customer. The maintainability requirements are shown in table 22.3

ID	Requirement	Priority
NFMA-1	Modules that may be moved to a lower level of *Glisa* shall be marked in the user documentation and in the source code, in case the customer wants to enhance the performance characteristics by implementing these modules in faster running code.	High
NFMA-2	All Python programming shall be in accordance with the *pep08* and *pep257* standards.	High
NFMA-2	All produced code shall be unit tested.	High

Table 22.3: Software system attributes: Maintainability

22.4 Portability

The portability of *Glisa* has low priority, since the system will be used mostly in the 3D lab. It must function on the operating system available in that lab, and it must be easy to distinguish which parts must be altered when moving *Glisa* to another operating system. This leads to the following requirements, listed in table 22.4

ID	Requirement	Priority
NFMA-1	The operating system specific modules shall clearly be marked in the user documentation and in the source code, so it is easy to distinguish these from the operating system independent ones.	High
NFMA-2	*Glisa* shall function on Debian Unstable	High

Table 22.4: Software system attributes: Portability

Chapter 23

Required documentation

This section describes the documentation that the project will generate and why this documentation is needed. Good documentation is important to the customer, who intends to integrate *Glisa* with their existing software product, to enable the developers to understand the structure of the library and use the API correctly. In addition, it is important to the project group, as a means of communication, reference and for remembering decisions.

The documentation to be produced consists of four documents:

- System documentation.
- API (technical) documentation.
- Installation manual
- User manual

23.1 System documentation

By system documentation, we mean the project report, in particular the requirements specification, design and implementation documents. The intended use of this documentation is to enable the *SciCraft* developers to understand the choices made in designing *Glisa*, and to explain how the system is built from cooperating software modules. Additionally, the test documentation will build confidence in the quality of the product.

All system documentation is written using the LaTeX type-setting system and is supposed to be high-level, leaving out the technical details to the API documentation.

23.2 API documentation

The API documentation consists of detailed technical documentation for all classes, functions and variables and is intended to be helpful when using, extending or changing the library's functionality. This is both for the project group, during implementation and testing, and for the *SciCraft* developers, during adaption and maintenance.

We choose to include the API documentation in the source code and generate the document by using freeware tools, such as *doxygen* or *kdoc*. This means that the documentation will be available along with the documented entities, and when the project group members commit to updating the documentation when changing any functionality, this constitutes a way of keeping the documentation up-to-date with minimal overhead for the implementors.

23.3 Installation manual

The installation manual is intended to describe how to install *Glisa*, both from binaries and from source code.

23.4 User manual

The user manual should provide a detailed description of how to use the demo application, which shows the functionality of *Glisa*, and how to operate the calibration application. Additionally, there should be a manual for the gesture training support application.

Part IV

Construction Documentation

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Chapter 24

Introduction

This is the construction document of group 11 in the course *TDT4290 Customer driven project*. The purpose of this document is to make use of the knowledge from the pre-study phase in order to transform the requirement specification into an actual system design. This process should be carried out satisfactory enough for the document to serve as basis for the implementation phase. This implies that the document should provide precise directions regarding the implementation of *Glisa*.

As is elaborated in this document we have decided to perform an incremental construction - implementation process to maximise the utilisation of available resources in the project, meaning that some of the group members can start implementing an increment, while others carry out further construction.

The construction document is divided into the following succeeding chapters:

- Chapter 25 - Architecture of *Glisa*, which explains the overall system design.
- Chapter 26 - Development plan, which provides an execution plan for the construction and implementation of *Glisa*.
- Chapter 27 - Description of the increments, which describes the three intended increments in detail.
- Chapter 28 - Programming methods and tools, which describes intended implementation tools and methods for the development of *Glisa*.

Chapter 25

Architecture of *Glisa*

25.1 Overview of design

This chapter will present the general architecture of *Glisa* and the demo application that will use the library. Figure 25.1 gives a view of *Glisa* divided into modules organised by functionality. The library consists of two layers and two additional support applications. The application that uses *Glisa* will typically be a graphical application, and in our case a demo application that uses VTK for rendering. The next subsections describes the individual layers and what functionality they provide. A short description of the support application is also provided.

25.1.1 Low level layer

Since the drivers do not include a Python interface, at least some part of *Glisa* must be written in C or C++. In addition the library will be sampling at approximately 60 Hz from the HCI- devices. This puts efficiency requirements on the code, and we have therefore chosen to write most of the low level layer in C++, with Python interfaces that the middleware can use. Interaction with gloves is done using drivers supplied by the manufacturers. Modularity, in the sense that parts of the library can be replaced, is important to the customer. A wrapper will therefore be built around the drivers for the *5DT DataGloves* (see chapter 16.2 in the pre-study), so that these gloves can easily be replaced by virtual gloves from other manufacturers later. After the evaluation of the different choices for low level drivers in the pre-study, we decided to use also the drivers provided by the manufacturers for *Flock of Birds* (see chapter 16.3 in the pre-study). During the implementation phase however, we encountered problems using these drivers, and could not get them to work properly. We therefore abandoned these drivers, and implemented the drivers for *Flock of Birds* ourselves, reusing parts of the source code from *Hololib* (see chapter 16.4 in the pre-study). As for the modularity demand we have an interface for a generic positioning device, which is implemented by the specific *Flock of Birds* driver.

Above the drivers for the HCI- devices, there is a module that performs polling on the devices. The number of polling samples per second is set by the user, through the middleware library. Output from position device and glove are paired together, and a time stamp for the sample is added. The samples are organised in a queue and transferred to the middleware on request.

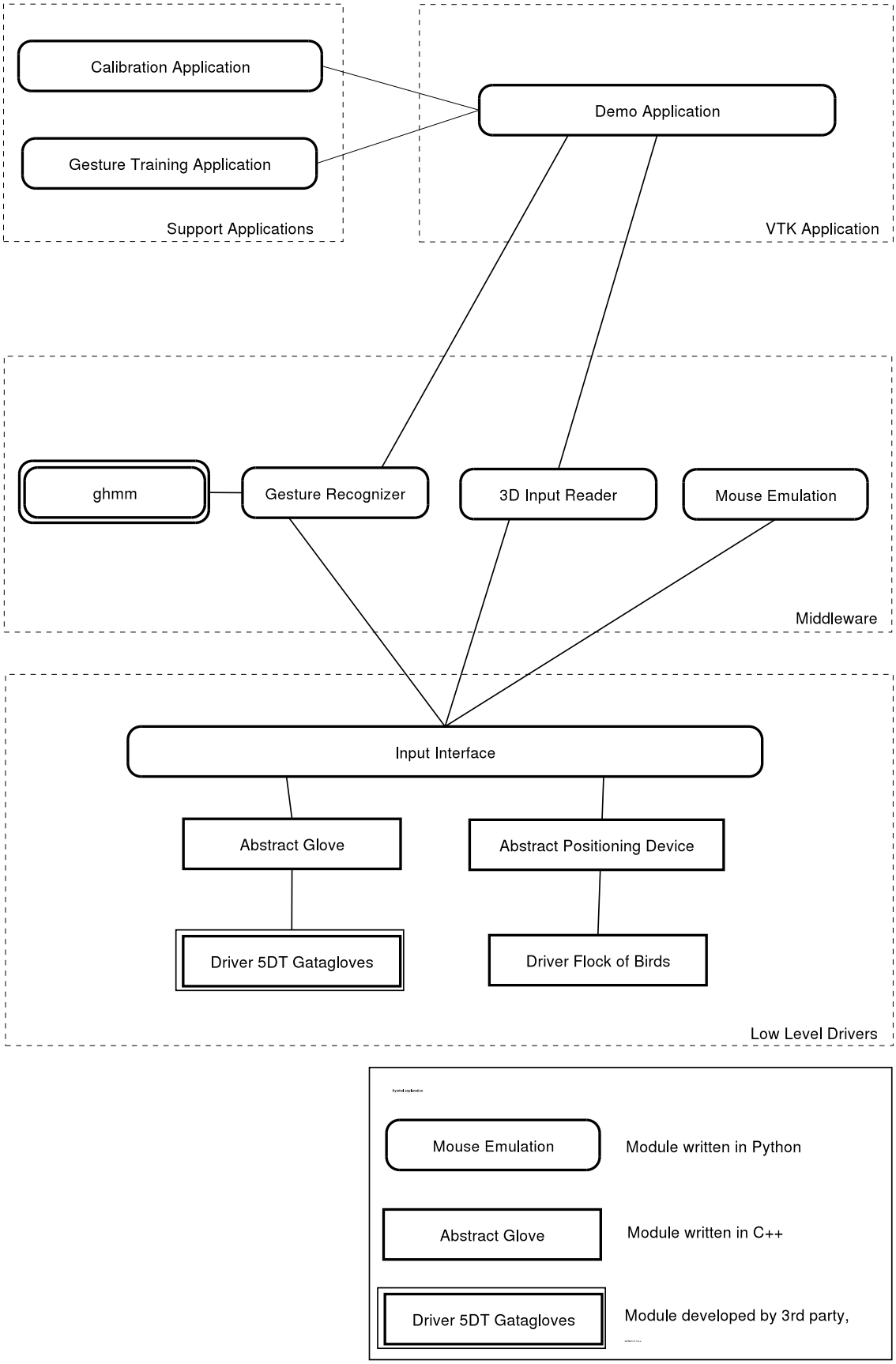

Figure 25.1: *Glisa* divided into modules

25.1.2 Middleware layer

The middleware layer will be written in Python, and this is the layer that will function as an API for the programmer. The data flowing between the middleware and the low level layer will mainly be samples from the input devices. Additionally there must be ways to communicate program specific settings to the lower level. The main purpose of the middleware is computation of virtual coordinates from device samples, so that a program using *Glisa* can use output values directly without the need to map between different coordinate systems. The middleware must also be able to recognise gestures performed by the user, and to translate input from the gloves to mouse movement. We have thus divided the middleware into 3 modules:

- 3D input reader.
- Mouse emulation.
- Gesture recogniser.

The gesture recogniser uses an external library named *GHMM* for GNU Hidden Markov Models Library, instead of the library discussed in the pre-study, *Torch*. We have become aware of this library after the pre-study phase and it seems easier to use since it is implemented in Python, as the rest of the middleware layer. The exact functionality of these modules will be defined in the increments implementing them, see chapter 27.

25.1.3 Support applications

An application using *Glisa* may need to use one or both of two support applications included in *Glisa*. The calibration application is a small application that lets the user calibrate the positioning device. If this is not done, it will be impossible to get useful coordinates from *Glisa*. The application is described more in section 27.1. The gesture training application is an application that lets an user define and train more gestures that the system should recognise. The user in this case will typically be a programmer that wants to use *Glisa* in his/her program, but it can also be a normal end user if *Glisa* is included in a program that lets the users define new gestures themselves.

Chapter 26

Development plan

This chapter will provide a brief overview of how the construction and implementation of *Glisa* will be executed.

26.1 Incremental development model

Developing the detailed design for an entire system at once may be a difficult task. Often, one will not be able to identify all required elements prior to the start of the implementation phase, and an incremental development model may therefore be beneficial to the project if one has a sufficient high-level design. Another advantage is that when one is limited on time, as this project is, incremental development creates fully functional products with reduced functionality without wasting work on designing parts of the system that will never be implemented.

We find the above advantages to be good reasons for choosing incremental development for this project. This means that we will divide the construction and implementation of *Glisa* into 3 parts, where each part covers a subset of the requirements for the end product. One increment is executed by first designing the increment, and then starting directly by implementing it. During the implementation phase we might have to go back and revise the design before continuing the implementation. After we feel confident in our implementation, module testing must be performed to ensure that we do not have to go back and modify the implementation later. Module testing might lead to revealing faults which would mean more implementation and possibly more redesign.

But even though we've separated the development into 3 increments, we will not always be able to fully complete one increment before we start on the next. This is because of time constraints.

26.2 Scope of each increment

In increment 1 the main focus will be to establish communication with the Human Computer Interaction (HCI) devices. As all other functionality in *Glisa* will depend on this communication, it

is of high importance that this part is done properly and with adequate testing. As each increment should also meet a subset of the requirements, we will in increment 1 try to use the gloves to control pointers in a 3D environment. This means that we will have to create a 3D environment, and also create a calibration module for *Glisa*.

Increment 2 will concentrate on making *Glisa* functional in a normal program. To accomplish this it should be possible to use the gloves to control a normal mouse pointer. The ability to change between this mouse pointer mode and the 3D pointer, implemented in increment 1, must also be added.

Gesture recognition will be the main point of focus in increment 3. As it is a quite complex part of *Glisa* and also not a requirement with top priority, we have chosen to delay the implementation of this part until the last increment.

The details of the scope of each increment is specified in chapter 27.

26.3 Schedule

The available time for the implementation of *Glisa* is three weeks, and we aim to complete one increment each week.

Design of increment 1 is to be completed in week 42. In week 43 we can start implementing the increment, and testing should begin in the start of week 44. Design of increment 2 can be started in the end of week 43, and implementation of the increment should start directly early in week 44. Testing can start 1 week later in week 45. Increment 3 can be designed concurrently with the implementation of increment 2 in week 44. Both testing and implementation of this increment will have to be done within the end of week 45. A Gantt diagram which shows this schedule can be found in the project directive, appendix A.

Chapter 27

Description of the increments

27.1 Increment 1

The first increment in the development process will focus on the system's ability to use the gloves as pointing devices in a 3D environment. By only implementing a small subset of the requirements initially, we will quickly be able to gather feedback from the customer as to whether we have interpreted the requirements in the same way.

27.1.1 Requirements covered by increment 1

Increment 1 will focus on meeting the following requirements specified in the requirements specification:

- SA-2 The system shall be able to calibrate the 3D environment with regards to mapping of real 3D space versus projected 3D space.
- A-7 The application must track the movement of both gloves and provide a graphical representation of the pointers.
- A-8 The application must be able to detect selection of objects in the 3D space.
- A-10 The application shall enable grabbing and releasing of objects.
- A-11 The application shall enable movement and rotation of grabbed objects.
- A-12 The system shall facilitate navigation through the 3D space.
- M-1 The system shall run in a continuous loop, polling for and distributing events to the application.
- M-2 The system shall collect events and release them to the application upon request.
- M-7 The system shall report three dimensional input data for glove position and rotation to the subscribing software entities when it is in *3D input device* mode.

- M-9 The system shall be able to report finger flexure in the range [0.0, 1.0] upon request from the application.
- M-12 The system shall be able to establish a mapping between physical and virtual space.

The reason for choosing these requirements is partly based on the priorities set by the customer for the end product, and partly because they will provide a quite limited set of functionality that needs to be implemented in the lower layers of the software. The ability of the system to let the user move a pointing device in a 3D environment is absolutely necessary for the project as it forms the customers main motivation for the project. Before this can be accurately achieved however, the software will have to be calibrated, and thus a small application for calibration will have to be developed.

27.1.2 Design of increment 1

Figure 27.1 and figure 27.2 displays the classes that must be implemented in increment 1. The classes belonging to the demo application have been shown in a separate figure as only *DemoApplication* will interact with the other classes in *Glisa*. Some of the classes will only be partially implemented as some of the functionality descends from requirements not covered in this increment. Specifically this holds for the classes *DemoApplication* and *GraphicsModule*.

CalibrationApplication This class will provide all functionality needed to calibrate *Glisa*. It contains only one method which will start the calibration application when called. The application itself should be a VTK widget displaying a number of small boxes. The user must then pick each of the boxes in succession, so the system can calculate how raw input data from the transmitter must be transformed to match the 3D environment. The method returns a 4x4 matrix with these transformations. This functionality has already been developed in *Holomol* (see chapter 16.4 in the Requirements Specification) but must be translated into the Python programming language.

DemoApplication This class will start all the other modules, and will be used to show the functionality of *Glisa*. It must start by starting the calibration application and the *Control* from *Glisa*. When it receives the transformation matrix, it can start its *GraphicsModule* and set the calibration matrix for *Glisa*. It must implement the *Input3DListener* interface and register with the *Input3D* object. When this is done, it will receive actions performed by the user through the methods defined in *Input3DListener*. The application must decide how these actions should be translated into method calls on *GraphicsModule*.

GraphicsModule This is the part of the demo application that generates the visual 3D environment that *Glisa* will be used to control. This environment will be generated in VTK, but in increment 1 it will be quite simple. In order to have objects that can be selected, the application will display several cubic boxes, in different colours. A separate class *Cube* will be made to generate these boxes. To make a selection of a box, the method *select_object()* is used. This method will select the object closest to the coordinates given as parameters. In addition, the *GraphicsModule* must have the ability to display graphical feedback of where the pointing devices are located. A class, named Pyramid, will implement this functionality. The methods in *GraphicsModule* to set these positions are *set_left_hand_position()* and *set_right_hand_position()* with 3 coordinates (x, y and z) as

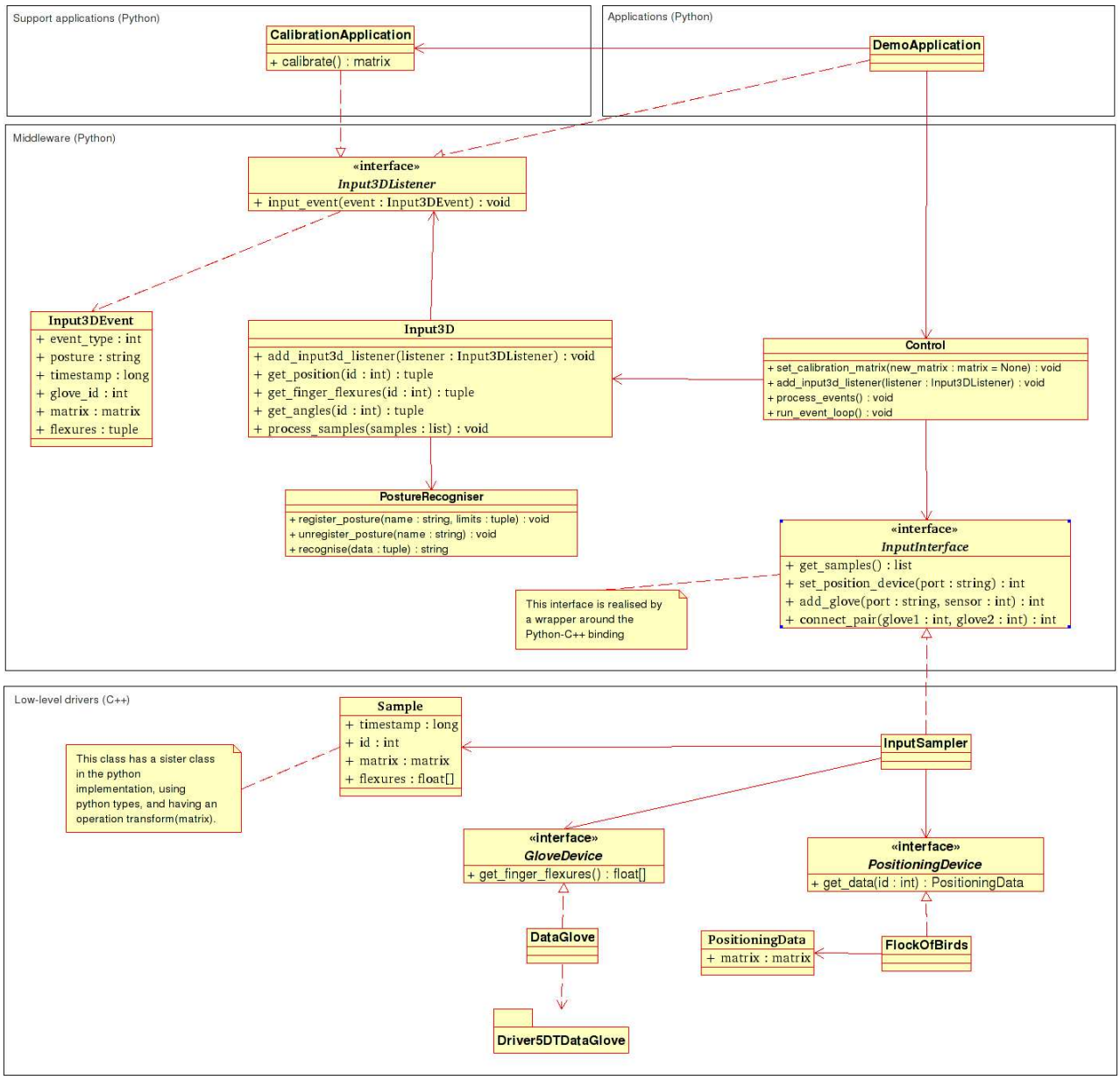

Figure 27.1: Class diagram of *Glisa* in increment 1

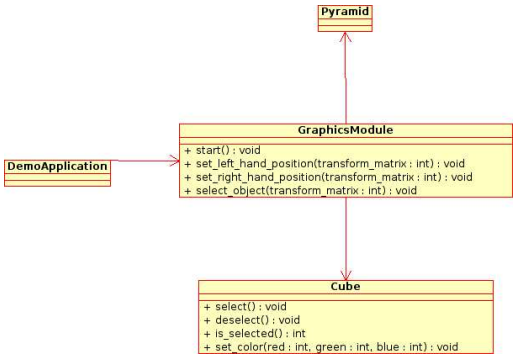
Pyramid
GraphicsModule
+ start() : void
+ set_left_hand_position(transform_matrix : int) : void
+ set_right_hand_position(transform_matrix : int) : void
+ select_object(transform_matrix : int) : void
DemoApplication
Cube
+ select() : void
+ deselect() : void
+ is_selected() : int
+ set_color(red : int, green : int, blue : int) : void

Figure 27.2: Class diagram of the demo application in increment 1

parameters. The demo application will of course have to be altered and expanded in later increments to show all functionality in *Glisa*.

Control The *Control* class will run continuously in a thread of its own and perform polling, by calling *get_samples()* on the *InputInterface*. If a calibration matrix has been registered, the samples are transformed using this matrix before they are passed to *Input3D*. The thread is started and controlled by the application.

Input3D The *Input3D* class will generate events that it sends to all applications registered as *Input3DListener*. The events are objects of the type *Input3DEvent*. These events are generated whenever the system detects that one of the hands moves, or a posture is performed. Postures will in increment 1 be selection postures as described in the requirements specification, requirement A-8 chapter 21.1. The *Input3D* class receives samples transformed to application object space through a call to the function *process_samples*, and these are wrapped in new *Input3DEvent*s and sent to all listeners.

InputSampler The *InputSampler* is the class in the low level layer that gathers all data from the input devices connected to *Glisa*. It runs continuously in a thread and performs polling on the drivers. The method for doing the polling is to first get the finger flexures for one glove from a *GloveDevice* object. Then it performs a call to the method *get_data()* in the *PositioningDevice* object, with the correct id for that glove as a parameter. The data gathered from *GloveDevice* and *PositioningDevice* is defined as one sample for one hand, and is stored in a *Sample* object. *Sample* objects must be stored in a list, and *InputSampler* must at any time keep a marker on the list of which *Samples* the *Input3D* object has received. When the method *get_samples()* is called on *InputSampler*, a list with all *Samples* generated since the last call must be returned.

Sample This is a data wrapping class. Besides the matrix and finger flexures of a hand, a *Sample* object must also contain an id for the hand, and a time stamp that tells when the sample was taken.

FlockOfBirds This is a driver for *FlockOfBirds* implemented by the project, which implements the *PositioningDevice* interface and provides the necessary functions to initialise and run the *Flock of birds*. When *get_data()* is called, the class returns a standard C++ 4x4 matrix that contains the transform matrix that yields the most recent position and angle of the *FlockOfBirds* sensor connected to the hand defined by the parameter *id*.

DataGlove The *DataGlove* class is a realisation of the *GloveDevice* interface. One object of this class must be instantiated for each hand connected to *Glisa*. It is a direct mapping of the methods defined in *DataGlove* to the functions in the drivers.

Driver5DTDataGlove This package is provided by the manufacturers of *5DT DataGlove 5*. The driver must operate in streaming mode so that polling from *Glisa* will be efficient.

27.1.3 Interaction between the classes

As mentioned in the description of the classes, in increment 1 two threads will be running in *Glisa* besides any threads that will possibly be running in the application and in the drivers. An overview of the operations performed in these two threads are depicted in figure 27.3 and in figure 27.4.

Figure 27.3 shows how an application may request events from the middleware layer as described in requirement M-2 (see chapter21.3 in the requirements specification). The *Control* instance gets samples from the *InputSampler*. Each of these samples multiply their matrix with the calibration matrix, using the *transform()* method. Then, samples are sent to the *Input3D* module that recognises postures and creates *Input3DEvent*s that are distributed to the application. For continuous event distribution, as described in requirement M-1, the thread created for control runs in the function *start_event_loop()*, which continuously calls *process_events()*.

The polling of the drivers is shown in figure 27.4. Here the *InputSampler* performs the polling first on a *DataGlove*, and then on the *FlockOfBirs*. The data from these to objects are placed in a *Sample* object.

27.2 Increment 2

The second increment focuses on making *Glisa* functional in a typical user program. This is accomplished by adding mouse emulation to the functionality with increment 2. In addition, requirements that were not finished during increment 1 will be implemented. Specifically, this means that some of the functionality of increment 2 may be delayed to increment 3, and that some requirements may not be implemented at all.

27.2.1 Requirements covered by increment 2

Increment 2 will focus on meeting the following requirements specified in the requirements specification:

- A-1 The application shall provide a method for changing from 3D input mode to 2D mouse emulation mode.
- A-2 The application shall provide a method for changing from 2D mouse emulation mode to 3D input mode.
- A-3 In 2D mouse emulation mode the user shall be able to use the hand to emulate left clicking on the mouse.
- A-4 In 2D mouse emulation mode the user shall be able to use the hand to emulate right clicking on the mouse.
- A-5 In 2D mouse emulation mode the user shall be able to use the hand to move the mouse pointer.

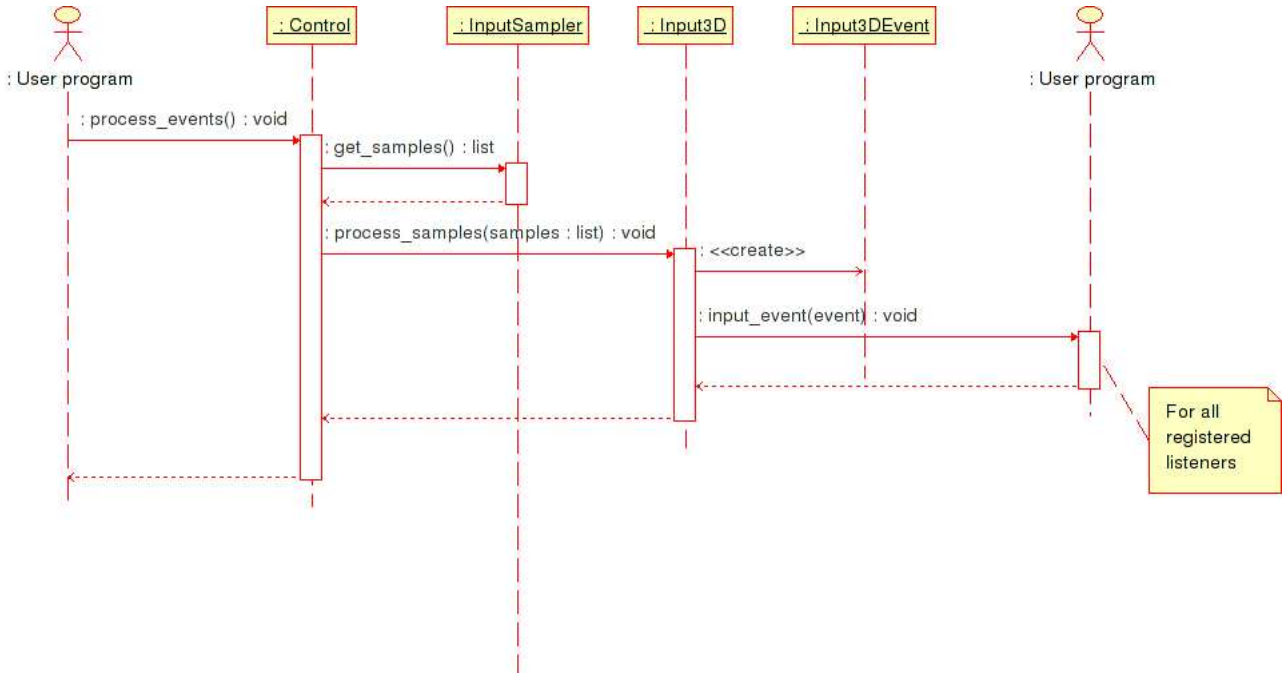

Figure 27.3: Sequence diagram that shows how an application receives events

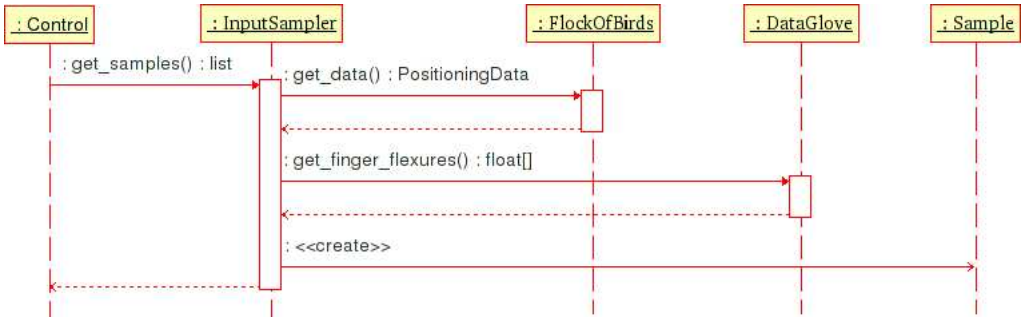

Figure 27.4: Sequence diagram that shows how *InputSampler* performs polling on the devices

- A-10 The application shall enable grabbing and releasing of objects (from increment 1).
- A-11 The application shall enable movement and rotation of grabbed objects (from increment 1).
- A-12 The system shall facilitate navigation through the 3D space (from increment 1).
- M-8 The system shall recognise grab and release events and notify subscribing software entities when these are performed.
- M-10 The system shall report events of the type; mouse move, mouse button down and mouse button up to the subscribing software entities when in *Mouse emulation mode*.
- M-11 The system shall always show in which mode it is operating.

27.2.2 Design of increment 2

Figure 27.5 displays the new classes that must be implemented in increment 2, as well as extensions that must be made to the classes implemented in increment 1. Figure 27.6 shows the modifications that will need to be done in the demo application.

The following sections describe classes and modules that are new or changed from increment 1.

Control To satisfy requirements A-1 and A-2, the *Control* class must be extended to maintain *Glisa*'s state and direct samples to the correct class. State diagram is shown in figure 27.7.

MouseEmulation The *MouseEmulation* class of the middleware translates input samples delivered from the *InputInterface* via the *Control* class to calls to the operating system's mouse driver. This includes recognition of certain finger configurations as postures (hence the association to *PostureRecogniser*) and projection of 3D coordinates to 2D screen coordinates.

OperatingSystem This package represents the dependency of the *MouseEmulation* class on operating system-specific services.

GraphicsModule Methods are added to show the new functionality in the middleware. The methods added make navigation, grabbing of objects, and moving objects possible.

27.3 Increment 3

The third increment completes *Glisa*, adding support for gesture recognition and selection of several objects.

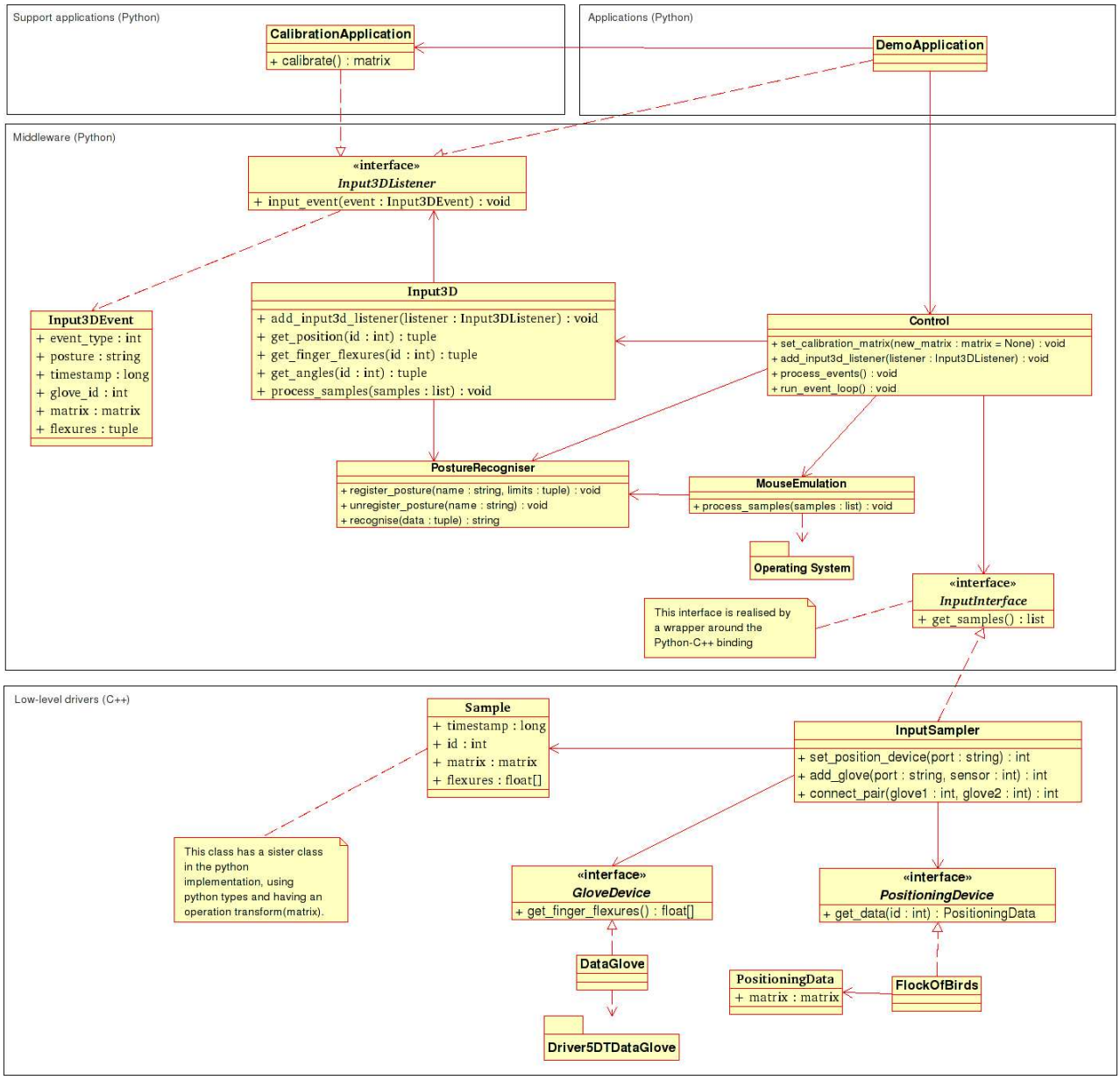

Figure 27.5: Class diagram of increment 2.

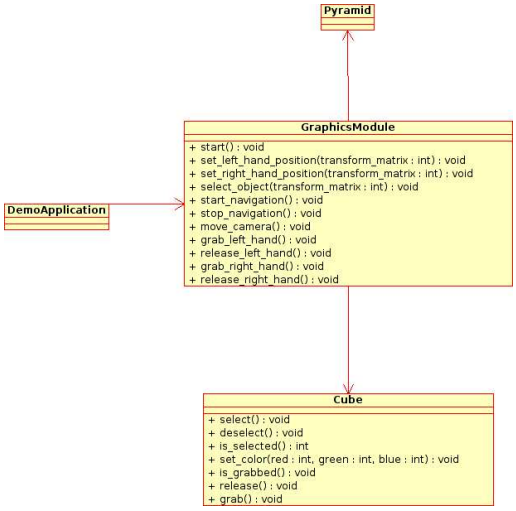

Figure 27.6: Class diagram of the demo application in increment 2.

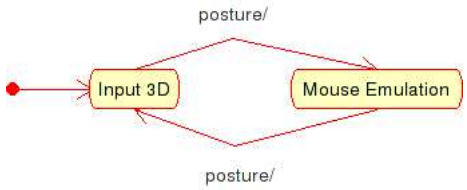

Figure 27.7: State diagram for `Control` class.

27.3.1 Requirements covered by increment 3

Increments 3 will cover the following requirements:

1. SA-1: The application shall facilitate training of new gestures and add them to the system.
2. A-6: The application shall recognise performed gestures.
3. A-9: The application shall facilitate the selection of several objects in 3D mode by marking an area.
4. M-3: The gesture recognition system shall be programmed by training.
5. M-4: The gesture recognition system shall be able to recognise certain sequences of actions as previously trained gestures and report this to the application.
6. M-5: The gesture recognition system shall be able to identify a set of default gestures.
7. M-6: The gesture recognition system shall enable the application to subscribe gesture events, and enable and disable recognition of individual gestures.

27.3.2 Design of increment 3

Figure 27.8 displays the classes that must be implemented in increment 3, along the classes implemented in increment 2. Figure 27.9 shows the new changes in the demo application.

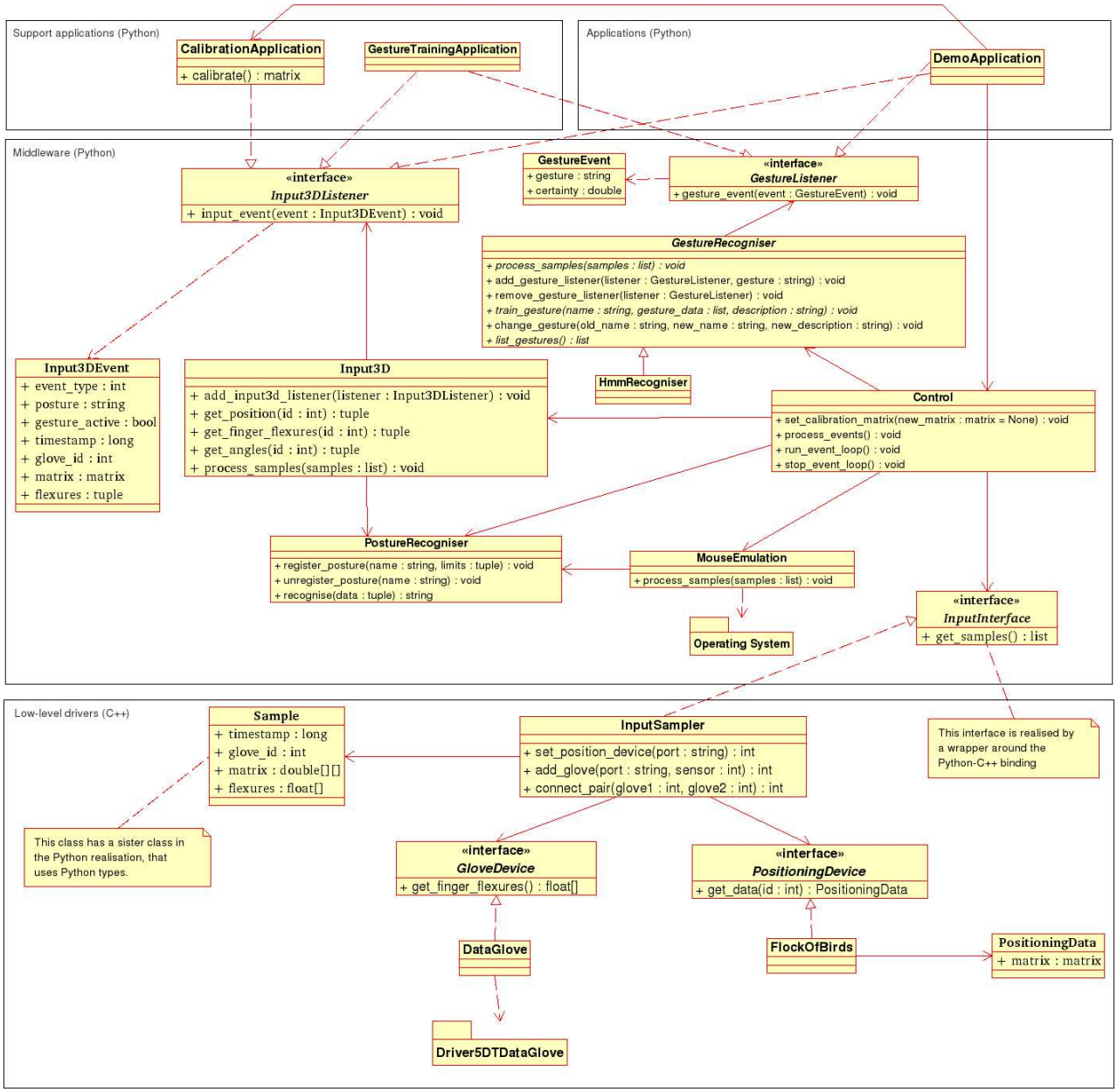

Figure 27.8: Class diagram of increment 3.

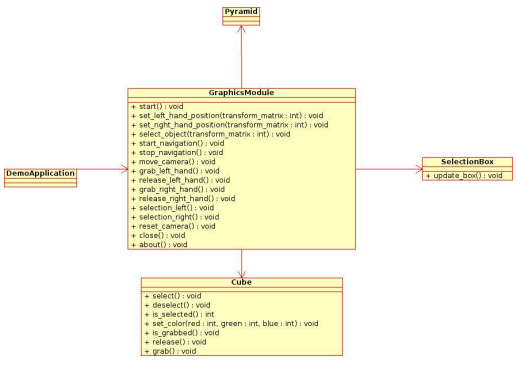

Figure 27.9: Class diagram of the demo application in increment 3.

The following sections describe classes and modules that are new or changed from increment 2.

Control To enable operation of the gesture recogniser, samples must be directed to it, and this is done by the `Control` class. Additionally, it is specified in requirement A-6 that gestures are only recognised when a specific posture is performed, and so the `Control` class needs to segment the incoming data into chunks representing gestures before passing them on to the recogniser. The state diagram is shown in figure 27.10.

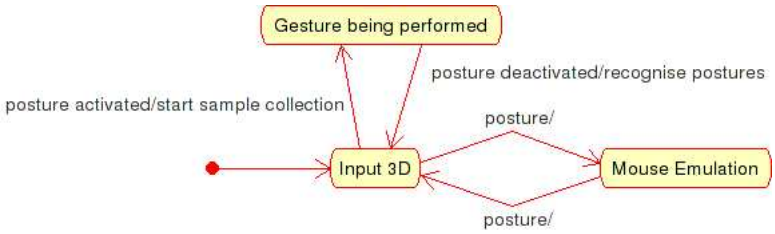

Figure 27.10: State diagram for `Control` class in increment 3.

GestureRecogniser An abstract class represents a general gesture recogniser, enabling implementation of other machine learning strategies at a later stage. In accordance with requirement M-6, functionality for subscribing and unsubscribing events are present. The function performing recognition (`process_samples()`; requirement M-4), expects the list of samples that is received to contain the samples representing one complete gesture, and the function for training (`train_gesture()`; requirement M-3) expects a list of such lists of samples.

GestureListener Gesture events are passed over the `GestureListener` interface when a gesture is recognised.

GestureEvent When a gesture is recognised, the application receives a `GestureEvent` with the name of the recognised gesture and the certainty with which it was recognised.

HmmRecogniser The `HmmRecogniser` is a realization of a `GestureRecogniser` using Hidden Markov Models (see the pre-study document).

Demo application Support for selection box is added with the class *SelectionBox* and a couple of new methods in *GraphicsModule*. In addition a few methods for handling window events have been added.

Chapter 28

Programming methods and tools

This section describes the concrete methods and tools that will be used during the development of *Glisa*, along with a brief description of how to use them and a pointer to further information.

Standardising programming tools aims at increasing the quality of the finished product and shortening development time. This is accomplished if the tools lead to higher-quality code and thus less debugging effort. However, this success depends on the programmers' will to follow conventions and ability to use the tools correctly (and all the time).

28.1 Development environment

The choice of an editor is a personal choice, and the programs and utilities mentioned in this section are mere suggestions to ease development.

28.1.1 General tools

There are tools that support many languages, including C++ and python. The following list states some typical examples:

- *emacs* Emacs is an editor with long traditions and many advanced editing features, no need for a mouse, and loadable modules for extension available for most development tasks.
- *eclipse* The eclipse platform is a development environment that is fully extensible, and a vast amount of plugins is available. Sadly, many are commercial, and the program sometimes runs slowly (being a Java-program).
- *KDevelop* Bundled with the *K Desktop Environment (KDE)*, this tool has support for development in many languages (and typesetting with LaTeX), including python and C++. KDevelop is installed at the group's computer at *doc*.

Printing of source code (including LaTeX) may be done using *GNU enscript* or *a2ps*, and source code can be formatted by using the tool `astyle`.

28.1.2 Python development

For developing python programs, several tools are available. The tool bundled with python is *IDLE*, an advanced text-editor with a python shell. For more advanced development, an IDE such as *eric* is recommended. This program integrates with the python debugger (see section 28.4.1), the *PyUnit* unit testing framework (see section 28.2.1) and a refactoring tool called *Bicycle Repair Man*. In addition, it has loads of advanced functionality, including (but not limited to) integration with user-interface design tools, scripting support, code line counting, project management and code completion.

28.1.3 C/C++ development

A vast amount of tools may help C/C++-development. One is *eric*, as introduced in the previous section, another is *Kdevelop*, the development package bundled with the desktop environment *KDE*. This program is specifically directed at C/C++-development and has many advanced features, including makefile configuration and generation and integration with debugging tools as *gdb* and *valgrind* (see section 28.4.2).

28.2 Unit Testing

Unit Testing is instituted in the eXtreme Programming (XP) discipline, and aims to detect coding errors and erratic changes as early as possible, and in an automated manner. This is done by keeping a test program along with each and every module or function in the system, that may be run automatically and that generates errors when the module in questions functions incorrectly. If the programmers run all tests before committing a change to the central repository, they can feel confident that their newly added code did not break existing functionality (that is, if they change the code and not the tests if the tests fail).

In conjunction with unit testing, there is an established terminology:

Test case A single scenario, or multiple tightly related scenarios, set up for automated testing.

Test suite A collection of related test cases. One test suite often corresponds to one module.

28.2.1 Python unit testing – PyUnit

This chapter is researched from the PyUnit documentation. The example used demonstrates tests for the code in module *mymod*, which is shown in code listing 28.2.1. It implements a simple counter

class.

Code Listing 28.2.1 (mymod.py)

```
class Counter:
    """Simple counter class."""
    def __init__(self, val = 3):
        """Create a simple counter, starting at 3."""
        self.value = val

    def inc(self):
        """Increments the counter."""
        self.value += 1
```

Python unit testing is performed by the `unittest` module. Writing a test case is done by importing the module and subclassing `unittest.TestCase`. This has numerous syntax forms, one of which is shown in code listing 28.2.2, an example of embedding several tests in one test case. The example also shows how a test suite is built. Several test suites may be nested simply by creating a test suite and adding other test suites instead of tests.

Code Listing 28.2.2 (mymod_test.py)

```
import unittest
import mymod

class MyTestCase(unittest.TestCase):
    """Simple test case for module mymod."""
    def setUp(self):    # optional method
        """This method is called before executing any of the tests."""
        self.foo = mymod.Counter()

    def tearDown(self): # optional method
        """This method is called after all tests, could be used to free any
        used resources, dispose windows, close files, etc."""
        pass

    def testDefault(self):
        """Check default value of 'value'."""
        assert self.foo.value == 3, "Default value is wrong."

    def testOperation(self):
        """See if increment operation performs correctly."""
        old_value = self.foo.value
        self.foo.inc()
        self.assertEqual(self.foo.value, old_value+1)

def suite():
    mymod_testsuite = unittest.TestSuite()
    mymod_testsuite.addTest(MyTestCase("testDefault"))
    mymod_testsuite.addTest(MyTestCase("testOperation"))
    return mymod_testsuite
```

28.2.2 C++ unit testing – CppUnit

C++ unit testing can be carried out using several different tools. For this project, *CppUnit* is chosen, as this tool seems to have a fairly complete documentation and sufficient functionality for our purposes. In addition, it has similarities with *PyUnit* used for python unit testing.

A simple test suite is shown in code listings 28.2.3 and 28.2.4, and illustrate the same tests as the python example in code listing 28.2.2. This code is assuming a class *Counter* with the same interface as the python class shown in code listing 28.2.1. The test suite in this example can be obtained by calling the static function `MyTest::suite()`.

Code Listing 28.2.3 (mytest.h)

```
#ifndef _MYTEST_H
#define _MYTEST_H

#include <cppunit/extensions/HelperMacros.h>
#include "counter.h"

class MyTest : public CppUnit::TestFixture
{
  protected:
    Counter *counter;

    CPPUNIT_TEST_SUITE(MyTest);
    CPPUNIT_TEST(testDefault);
    CPPUNIT_TEST(testOperation);
    CPPUNIT_TEST_SUITE_END();
  public:
    void setUp();
    void tearDown();

    void testDefault();
    void testOperation();
}

#endif
```

Code Listing 28.2.4 (mytest.cpp)

```
#include "mytest.h"

// Registers the fixture into the 'registry'
CPPUNIT_TEST_SUITE_REGISTRATION(MyTest);

void MyTest::setUp()
{
  counter = new Counter();
}

void MyTest::tearDown()
{
  delete counter;
}

void MyTest::testDefault()
{
  CPPUNIT_ASSERT_EQUAL(counter->value, 3);
}

void MyTest::testOperation()
{
  int old_value = counter->value;
  counter->inc();
  CPPUNIT_ASSERT_EQUAL(old_value, value);
}
```

28.3 Source code verifiers

Many common programming errors arise from typing mistakes, such as typing "=" instead of "==", or forgetting to break out of a switching-construct. These errors can often be spotted by automatic source-code readers. The process of finding such errors is often referred to as "linting", from the program "lint" on certain unices (verifies C code).

Source code verifiers can be wrong, and some runs result in loads of irrelevant warnings. It is up to the programmer to evaluate the warnings and decide if each particular warning is of importance, and whether or not to take action. Many warnings can be silenced by placing special comments in the code that tell the verifier (and others who read the code) that the apparent error is intentional.

28.3.1 Python verification

Verification of python code is essential, as there is a dynamic type system and no compiler (the interpreter checks basic syntax, but does not perform any semantic checks).

There are two popular verification tools for python, *PyChecker* and *PyList*. Since the latter does a more thorough evaluation and report, and since it may help enforce a consistent coding standard, this tool will be used in the project.

Usage of *PyLint* is as simple as running `pylint filename.py` from the command-line. It can even be run from within an editor (such as *emacs*). It outputs its messages in three categories:

- Warnings, indicated by a "W" in the output. Warnings are often problems that do not halt program execution, such as breach of coding conventions or missing documentation.
- Errors, indicated by a "E" in the output. Errors are problems that are likely to cause the program to fail, such as access to non-existent variables.

28.3.2 C/C++ verification

Verification of C code is done by the Open Source-tool *splint*, while C++-verification can be done by using *antic* (part of the *jlint* package). The need for this type of verification is not as urgent for C/C++-programs as for python programs, as the type system catches many typing mistakes.

28.4 Debugging tools

When writing computer programs, problems that relate to semantics rather than syntax arise because of a programmer's failure to foresee all possible consequences of the code she is writing. These semantical errors are referred to as "bugs", and they are tracked down by analytical reading of the source code, possibly assisted by using debuggers. Several types of debuggers exist, but the most popular is the dynamic debugger that lets the programmer step through the execution of the program, watching data during the process.

28.4.1 Python debugging

Python is distributed with a command-line debugger known as *pdb*, but using it directly from the command line is not a user-friendly option. Instead, it is compelling to use a front-end, such as *GUD* (Grand Unified Debugger, in *emacs*), *ddd* (Data Display Debugger) or an IDE (like *eric*).

28.4.2 C/C++ debugging

There are many C/C++-debuggers available. The one shipped with the GNU Compiler Collection (GCC) is *gdb*. Being a command-line tool, it is recommended to run the debugger through a front-end, like *GUD*, *ddd* or an IDE (like *Kdevelop*). Other compilers come with other debuggers.

In addition to the traditional debugger, it is also advantageous to check memory accesses, as stated in the pre-study document section on programming languages. The Open Source alternative on Linux is *Valgrind*, a command-line utility that checks all memory accesses, allocations and deallocations.

Valgrind invocation is done by invoking the command `valgrind`, giving the program executable as an argument. All arguments after the program name are passed on to the program to be debugged. An example of this is: `valgrind /bin/ls -l`. There are several helpful arguments that may be passed to valgrind, and they must be given before the program name:

- `--help` Show usage information.
- `-v` Produce more output.
- `--trace-children=yes` Also debug child processes.
- `--track-fds=yes` Keep a watch on open files.
- `--leak-check=yes` Search for memory leaks (warning: enabling this option is very time-consuming).
- `--show-reachable=yes` If checking for leaks, find out what blocks are still reachable (for instance, if a shared library allocated the block).
- `--suppressions=file` Sometimes, one comes across errors in system libraries, and this option specifies a file that list the erratic components to be ignored.
- `--trace-pthread=none|some|all` The amount of tracing done of threading-related code (none is the default).

A valgrind hint: Valgrind often suggests what command line options are relevant to use next, such as "For more details, rerun with: -v". Valgrind can be run through the *kdevelop* IDE, from version 3 and up.

28.5 C/C++ to python binding generator

Integrating different programming languages requires bindings to be written. Between C/C++ and python this may be done automatically, using a binding generator. Several exist, we will use *SWIG*, which seems to be the most mature and well-documented tool for this purpose.

Enabling a module for importing binding generation is done by adding the conditional code shown in code listing 28.5.1 to the header file of the module, assuming the module is named `sample` and is defined in `sample.h`.

Code Listing 28.5.1

```
#ifdef SWIG
%module sample
%{
#include "sample.h"
%}
#endif  // SWIG
```

Then, the binding is generated and compiled, as shown in code listing 28.5.2. These commands assumes the module consists of one file named `sample.cpp` with the header `sample.h` containing the code in code listing 28.5.1.

Code Listing 28.5.2

```
$ swig -c++ -python -Wall sample.h
$ c++ -I/usr/include/python2.3 -c sample_wrap.cxx
$ c++ -Wall -c -o sample.o sample.cpp
$ c++ -shared sample_wrap.o sample.o -o _sample.so -lpython2.3
```

Part V

Implementation

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Chapter 29

Introduction

This is the implementation document for group 11 in the course *TDT4290 Customer Driven Project*. This document provides a detailed description of the implementation of *Glisa*. This includes system documentation, user manuals, and coding documentation (API). Additional guidelines for coding are provided to explain coding style and ensure consistency during the implementation.

The implementation document is divided into the following succeeding chapters:

- Chapter 30 - System documentation, which describes all parts of *Glisa* in detail with special attention to tricky code and special features
- Chapter 31- User manuals, which provides user manuals for the three top level applications of Glisa.

The API is included as an appendix.

Chapter 30

System documentation

This chapter contains documentation on using *Glisa* within an application program, at a higher level than the API documentation. A regular programmer will probably only be interested in the middleware, but since *Glisa* is designed to be modular, a describtion of the lowlevel code is also presented. The applications will also be presented, since they are used to show the features of the *Glisa* library.

30.1 Demo Application

This is the system documentation of the demo application that is distributed with *Glisa*.

A couple of visualization expressions are used throughout this section, and they are explained below:

- World coordinates: The coordinate system defined in the virtual environment.
- Focal point: A point in the world coordinate system that the camera "looks" at, and focuses on.
- Camera coordinates: The coordinate system defined with the camera as its origin and the axis parallel and perpendicular to the vector from the camera to its focal point.
- Viewport coordinates: The coordinate system from the camera, width the perspective taken into account.
- Physical coordinates: The coordinate system set up by the *Flock of Birds*.

30.1.1 Overall description

The demo application is an example of how *Glisa* can be used in VR programs. It includes some simple features that we envision a full scale 3D application will use. It is not meant to be included in any other program, and code should probably not be copied directly. Instead it can be used to see

how to import *Glisa* in an application, and how data received from the library can be mapped into actions in a 3D environment.

30.1.2 Usage documentation

This section is not applicable to the demo application since the application should not be imported into other applications. For information on how to start and use the application, see the user manual, section 31.2.

30.1.3 Implementation details

The program starts with the calibration procedure, before the actual demo application is launched. The demo application is placed inside a Qt window. The reason for this is that we wanted to show how the gloves can be used to access menu options.

To receive events from *Glisa*, the demo application implements a `Input3DListener` interface. The implemented method is `input_event` which is called each time events are generated. The events the demo applications care about, are events generated when a hand is moved, when a posture is detected and when release of posture is detected. When the hand movement events are received, the demo application moves the pointer indicators on the screen according to the position defined in the event. The postures and their related actions are listed in table 30.1.

Posture	**State Action**	
pick	Performed	If an object is located at position of the hand that performed the posture, the object is selected.
	Released	<no action>
navigate	Performed	Each time a hand movement event is detected, the camera will rotate around its focal point, instead of the pointer indicator being moved.
	Released	The camera stops moving, and the pointer indicator starts tracking the hand movement again.
grab	Performed	If an object is located at the position of the hand that generated the grab event, the object is marked as grabbed. Each time a hand movement event is detected, the hand will move the grabbed object in addition to the pointer indicator.
	Released	The object is no longer marked as grabbed, and movement of the hand will no longer cause the object to move. The object stays selected.
selectionbox	Performed	A box is created to indicate a selection box, and each time a hand movement event is detected, in addition to the movement of pointer indicators, the selection box is altered so that two opposite corners track the position of the hands.
	Released	All objects within the selection box are selected. The selection box disappears.

Table 30.1: Posture and the actions they trigger.

In all events, both for the movement and postures, a transform matrix is supplied. The transform matrix gives the rotation and translation of a hand in viewport space. Since the objects are manipulated in world space coordinates, the demo application multiplies each matrix received from the middleware with an inverse viewport transform matrix. The matrix then describes rotation and translation of a hand in world space. The operations are displayed in the figure 30.1.

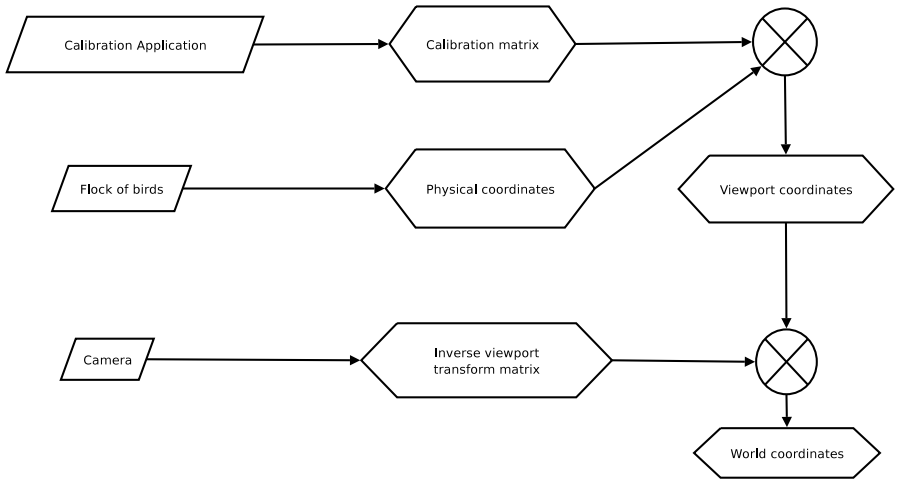

Figure 30.1: Transforms from physical to world space.

30.1.3.1 Postures

The postures was defined in the requirements specification, but during implementation and testing, we discovered that some of the postures were difficult or impossible to perform. Part of the reason for this is because of the poor quality of the gloves. Among the two pair of gloves we had available for testing, the left glove in one par had a defect little finger. The drivers would always return zero flexure on the finger. In the other pair, the left glove is unstable, in the sense that the same posture can give different measures. Especially the thumb can give very strange results, and this causes many of the postures to be either difficult to do, or far too easy to do. Because of this we had to disable mouse emulation with the left hand. With emulation enabled, the user would suddenly start moving the mouse when he actually tried to do something different.

In addition the posture for creating a selection box has been changed. The original plan was to use only the index fingers and require them to connect before the selection box was started. The problem with this approach was that we had no way of determining when the fingers connected. The demo application receives the position of the sensors attached on top of the hands, and not the finger tips. If an offset were added to the physical coordinates, detection of connecting fingers would be feasible but unfortunately this was never done. Instead the demo application now only requires a posture to be performed and doesn't care where the fingers are located. The posture to open a selection box is to extend the little finger, and flex all other fingers.

The posture for navigation is defined to be a flat hand in the requirements specification. This turned out to cause the system to enter navigation mode when the user did not intend to. The posture were thus redefined to require index and little finger to be extended, and the other fingers flexed.

30.1.3.2 Selection box

When a user performs the selection box posture with both hands at the same time, a translucent box is displayed which marks a selection volume. Two opposite corners of the box are located at the tip of the two pointer indicators, and when the pointers are moved, the box expands or shrinks. When the posture is released by any of the hands, all objects with center inside that selection box is selected. The way the box is generated is that the position of the two pointer indicators are transformed into coordinates in camera space by multiplying with the camera view transform matrix. Two opposite corners are set to the position of these coordinates, and the other 6 points are placed so that each edge will be either perpendicular or parallel to the vector from the camera to the focal point in the scene. Finally the points are transformed back into world space before they are set as points for a vtkPolyDataMapper.

30.1.3.3 Selection and grabbing of objects

An object will be selected or grabbed if the corresponding posture is performed when the hand, indicated by the pointer, is located inside the objects bounding box. This bounding box is calculated by *VTK* and is the smallest box with sides parallel to the axis in the world space, that encompasses all points in the object. Because of this, if a cube has been rotated so that its sides is no longer parallel with the axis in world space, the bounding box for that cube will be larger than the cube itself. It may thus be possible to select an object event though the pointer top is not inside the object. This is not a big problem though, and could be fixed by a more sophisticated calculation of the objects bounding boxes.

30.1.3.4 Requirements not met

In requirement A-7 in the requirements specification, it was stated that the pointer indicators should stop when they are moved outside the window. This were never implemented because of lack of time. Also in requirement A-8 it is defined that the application should calculate the probable position of where the pointer indicator should be located. This would have to be calculated because the positioning sensor is located on top of the hand, and not on the finger tip. The reason for why this were not done is that we discovered that it would have to be done in the library, possibly in the drivers.

30.2 Calibration application system documentation

This section is the system documentation of the calibration application. It describes how the application should be used and important implementation details.

30.2.1 Usage documentation

The purpose of the calibration application is to return a 4×4matrix giving the mapping between physical and virtual space. The matrix returned is represented as a numarray.array.

An example of how to use it is given in 30.2.1

Code Listing 30.2.1

```
import glisa.calibrator.calibrate

calibrator = glisa.calibrator.calibrate.CalibrationApplication()
calibration_matrix = calibrator.calibrate()
```

There are several parameters in the application which may be desirable to change such as the camera clipping range, window size, camera focal point etc. It is possible to do this by editing the configuration file glisa.xml, J.1. If these parameters are not set in the configuration file, they are given hard coded default values.

30.2.2 Implementation details

The calibration application is implemented using the library VTK. The transformation matrix is calculated using a landmark-transform which is based on the method of lest squares. The VTK class vtkLandmarkTransform implements this functionality. The three main methods used from this class are:

- SetTargetLandmarks(vtkPoints points)
- SetSourceLandmarks(vtkPoints points)
- GetMatrix()

The virtual coordinates each of the eight cubes initialized in the application are set as target points, and the coordinates of the position of the gloves when the user performs a pick of a cube are set as source points for the corresponding cube. When the method GetMatrix() is called, it returns a matrix representing a mapping between the virtual and physical space based on the coordinates given. To map the coordinates to a unit cube, the matrix returned by GetMatrix() is multiplied with the concatenation of the camera-view-transform-matrix and the camera-perspective-transform-matrix, the concatenations is called the camera-viewport-transform-matrix. This is illustrated in figure 30.2. Only three pairs of coordinates (virtual, physical) need to be set to be able use the method GetMatrix(). The eight pairs given in the calibration application ensures that poor picks made by the user will not make a severe impact on the correctness of the transformation matrix. In the requirement specification requirement SA-2 it is stated that the objects to be picked in the calibration application is to be balls. This was changed because of a much better 3D effect when using cubes.

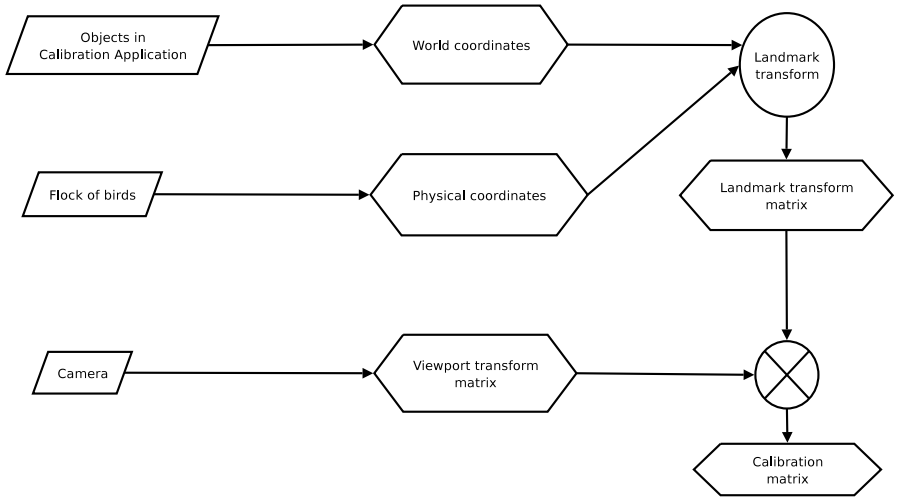

Figure 30.2: Computation of the calibration matrix

30.3 System documentation for the gesture training application

This is the system documentation for the gesture training application of Glisa.

30.3.1 Overall description

This application is the graphical user interface for training of new gestures and testing of already existing gestures. The application also provides a list of exiting gestures, which has already been trained and stored. The names and descriptions of a gesture are stored in a XML file and the corresponding data training set is stored in a separate .gst file. These gestures can also be edited and deleted.

When testing or training a gesture, feedback is given to the user by indicating when a gesture is being performed. A gesture is defined in our system to happen when the thumb is raised and the rest of the fingers are flexed. A label is set green when a gesture is being performed and red when not performing a gesture.

This gesture training application has been developed using the *Python-qt3* package.

30.3.2 Usage documentation

This section is not applicable to the gesture training application since this is a stand alone application that is not started from other parts of Glisa.

30.3.3 Implementation details

The gesture training application is kept in source/glisa/gesttraining under the module name gesture-training.py. This module contains two classes, where `WindowLayout` is the GUI class. The other class is `GestureTrainingApplication`, which first starts up the `CalibraitonApplication`, then starts up GUI class when done calibrating. `CalibraitonApplication` then listens for events of the kind `GestureEvent` and `Input3DEvent`.

The `WindowLayout` class is straight forward Qt GUI programming without any extraordinary features. As the *SciCraft* developers are believed to have better knowledge about Qt, it is left to them to develop a more complex GUI if wanted. Our priority was to get the underlying gesture training functionality in place. The different GUI components are initialized in the constructor and modified and operated on in accordance with user input. Signals and slots are used for handling actions when different buttons are clicked.

The `GestureTrainingApplication` implements `GestureListener` and `Input3DListener`. The `input_event(event)` method from `Input3DListener` is used to check whether or not the user is performing a gesture with either hand. This is done by checking for a `gesture_active` event and when one occurs the light feedback in the GUI is set green. When the same hand that performed the gesture is no longer `gesture_active` the light is set red. The `gesture_event(event)` method from `GestureListener` is used to determine what type of gesture the user is performing when he/she is testing a gesture. If the gesture is recognized, the name is displayed in the GUI along with the recognition probability of the gesture.

In the constructor of `GestureTrainingApplication`, a `Control` object is instantiated with glisa.xml as input parameter. This is a configuration file, which sets different attribute values in *Glisa*. The `Control` object is the `GestureTrainingApplication's` interface with the rest of *Glisa*.

By setting the `_gestrec` variable of the `Control` object to `self` in the constructor the `GestureTrainingApplication` is set to be the `GestureRecogniser` seen from the `Control` object. The `GestureTrainingApplication` thereby gets samples for processing when `Control` calls `process_samples(samples)`.

30.4 System documentation for the middleware

This section describes the use of the public interface of *Glisa* and the details of the library implementation.

30.4.1 Overall description

The middleware part of *Glisa* is the application's interface to the library, and provides an event-based interface as well as possibilities for polling.

Glisa enables the gloves as input devices, extending the concept used for mouse input into the

third dimension. Both special finger configurations, *postures*, and hand movement patterns in space, *gestures*, are recognized. Moreover, the gloves may be used to control the system's mouse pointer.

30.4.2 Usage documentation

Starting *Glisa* is done by instantiating a `Control` object and starting it in a thread of its own. This is shown in code listing 30.4.1.

Code Listing 30.4.1 (Glisa initialization)

```
import thread
import glisa.middleware.control

(...)

glisa_control = glisa.middleware.control.Control("/path/to/glisa.xml")
thread.start_new_thread(glisa.middleware.control.Control.run_event_loop,
                        (glisa_control, ))
```

The argument given to `Control`'s constructor identifies the configuration file, by default located in `/etc/glisa/glisa.xml` on UNIX and related systems. In this file, only the section defining the ports is mandatory. See appendix J.1 for details on the file format.

Glisa operates in two different modes:

1. *Input3D mode* — When operating in this mode, input- and gesture events are generated and distributed to all registered listeners.
2. *Mouse emulation mode* — When emulating a mouse, mouse events are generated and sent to the operating system. No input- or gesture events are generated.

Changing between the modes is performed by the user by performing predefined finger postures, and an event (`GlisaEvent`, see next the paragraphs) is emitted to the application.

The application interfaces *Glisa* through the `Control` class and the following interfaces:

1. `GlisaListener`: Conveys events of system state change, and when an exception is raised in the library.
2. `Input3DListener`: Conveys events regarding glove position, finger flexure and postures.
3. `GestureListener`: Conveys events regarding gestures.

The application's interface to *Glisa* is depicted in figure 30.3. This diagram includes the calibration application, which must be used prior to using any input from *Glisa*, and before the library can mouse emulation mode.

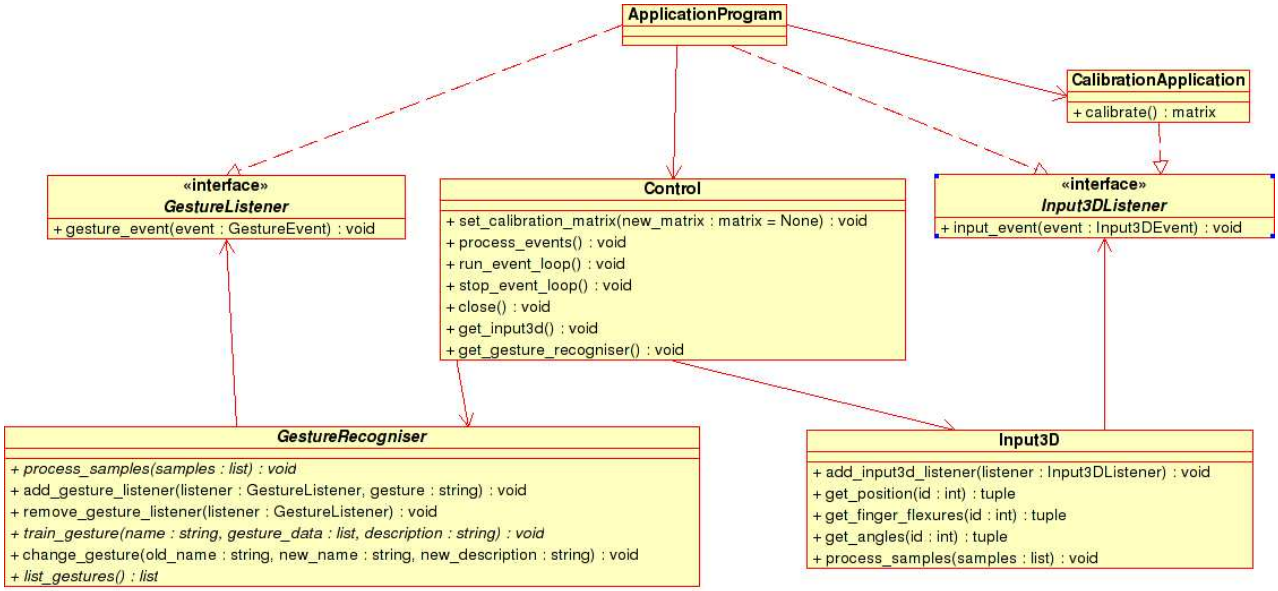
ApplicationProgram
CalibrationApplication
+ calibrate() : matrix
«interface»
GestureListener
+ gesture_event(event : GestureEvent) : void
Control
+ set_calibration_matrix(new_matrix : matrix = None) : void
+ process_events() : void
+ run_event_loop() : void
+ stop_event_loop() : void
+ close() : void
+ get_input3d() : void
+ get_gesture_recogniser() : void
«interface»
Input3DListener
+ input_event(event : Input3DEvent) : void
GestureRecogniser
+ process_samples(samples : list) : void
+ add_gesture_listener(listener : GestureListener, gesture : string) : void
+ remove_gesture_listener(listener : GestureListener) : void
+ train_gesture(name : string, gesture_data : list, description : string) : void
+ change_gesture(old_name : string, new_name : string, new_description : string) : void
+ list_gestures() : list
Input3D
+ add_input3d_listener(listener : Input3DListener) : void
+ get_position(id : int) : tuple
+ get_finger_flexures(id : int) : tuple
+ get_angles(id : int) : tuple
+ process_samples(samples : list) : void

Figure 30.3: An application's view of *Glisa*

An application may access the `Input3D` and `GestureRecogniser` objects through the accessor methods of `Control`, and register itself as a listener using the `add_*_listener()`-methods. When registered as a listener, the object will receive events through the methods of the corresponding interface. The `Input3D` class may also be queried on the values of the last sample, using the `get_*()`-methods. Registering for `GlisaEvents` is done using the `add_glisa_listener()` on `Control`.

30.4.3 Implementation details

This section describes specific details and algorithms related to the implementation of certain components.

30.4.3.1 3D input device implementation details

3D Input Device mode is implemented by translating samples to `Input3DEvents`, and recognizing postures using a `PostureRecogniser`. The functionality conforms to the requirements specification except that coordinate information is in matrix form rather than as separated components, because this representation proved more useful during the course of development. Note that since the low-level drivers normalize the finger flexure values, these are not altered by `Input3D` (as it would be an identity transformation, and without effect).

30.4.3.2 Gesture recognizer implementation details

The gesture recognizer is implemented using Hidden Markov Models through the *GHMM* library (http://ghmm.org). It uses a one-dimensional discrete model on a finite alphabet.

Preprocessing for training and recognition is done through the following steps:

1. Resampling at even time intervals, using linear interpolation.
2. Downsampling, reducing by halves each time by taking the mean of two and two adjacent samples.
3. Calculation of normalized speed vectors between means of two and two samples.
4. Scalar quantization of normalized speed vectors in a grid of equal resolution within a unit cube.

The recognition is then done by the Hidden Markov Models, by evaluating the probability of a given preprocessed sequence of inputs for each model representing a gesture, returning the name and likelihood of the most probable gesture. This likelihood is compared to a threshold before events are emitted to the application, and the likelihood is included in the event. Event subscription is kept on a per-gesture basis.

Hidden Markov Model evaluation is done using the forward algorithm described in the pre-study.

We have through the testing of this module discovered that the preprocessor is of vital importance for the performance of this module, and that the current preprocessor performs poorly when given complex gestures. This means in particular that the circle gesture specified in the requirements specification document is not recognized reliably. The mean recognition rate for the remaining three gestures is at 73,3%, and therefore the gesture recognizer fails to meet non-functional requirement NFP-1 of 80% recognition rate.

Additionally, requirement A-5 requires recognition of two simultaneous gestures, which is unsupported in the current implementation, and no exception is raised if convergence is not achieved. Another discordance is the lack of feedback to the application upon discarding an event, as demanded by requirement M-4.

30.4.3.3 Mouse Emulation Implementation details

Glisa will when operating in Mouse Emulation mode take control over the windowing system's mouse pointer. This is done through the functions in the `winsys` module, that wraps the windowing system specific calls. The first version of *Glisa* has only X Windows support and relies on the *X-Test* extension for sending button events.

The samples arriving from the `Control` class are transformed with a homogeneous projection matrix, and must be projected from three-dimensional homogeneous viewport coordinates to two-dimensional screen coordinates. This is accomplished by extracting the fourth column of the matrix and treating it like a four-component homogeneous coordinate, which is projected to three dimensions and the z component discarded (a parallel projection along the z axis).

Mouse Emulation does not conform to the requirements specification on mouse pointer position calculation. Requirement M-10 specifies that the position of the mouse pointer should be the projection of the index fingertip on the screen plane, while the implementation projects the sensor position, which in the current setup is on top of the hand. This is because of the technical problems related to adding an offset in the *Flock of Birds* driver.

30.4.3.4 Posture Recognizer

Several functions in *Glisa* are based on signalling through finger postures, and the `PostureRecogniser` class is responsible for identifying such postures. It does so by comparing five floating-point values representing finger flexure to five corresponding ranges expressed as the tuple (min, max). Postures are identified by string names and may be registered and unregistered dynamically. Note that when a set of flexures identifies two different postures, it is not defined which of the two that the library will signal.

Each of the classes `Control`, `Input3D` and `MouseEmulator` has its own instance of a `PostureRecogniser`, with their distinct postures configured through the xml configuration file for *Glisa*.

30.5 System documentation for the lowlevel

This section describes the use of the lowlevel part of *Glisa*. First a description of the interface, then a description of the implementation choices.

30.5.1 Overall description

The lowlevel part of *Glisa* provides samples from a positioning device and data gloves for a programmer. In the further discussion we will assume that any positioning device measures the position and orientation of multiple sensors in space. Only *5DT Data Glove* and *Flock of Birds* is supported, but *Glisa* has a modular structure, so support for other devices could easily be added. The lowlevel part is written in *C++*, but there exists *Python* bindings.

30.5.2 Usage documentation

Setting up the lowlevel part of *Glisa* is simple: The user only needs three classes, `InputSampler`,`Sample` and `SampleList`. The *Python* bindings have support of all these three classes.

To use glisa in C++, see code listing 30.5.1. Details for the methods, are described in the API documentation.

Code Listing 30.5.1 (Glisa initialisation)

```
#import "sample.h"
#import "input_sampler.h"

(...)

int samplingrate = 30;
InputSampler s* = new InputSampler();
try
{
//All this methods throw exceptions

  int i = s->add_glove("/dev/ttyS1");
  int j = s->add_glove("/dev/ttyS1");
  s->add_positioning_device("/dev/ttyS0",1,2);
  s->connect_pair(i,1);
  s->connect_pair(j,2);
}
cache(string s)
{
  cout << s;
  exit(1);
}
s->initialize(samplingrate);
SampleList* l = s->get_samples()
if(!l->is_empty())
{
  Sample* smpl = l->get_next_sample();
}
(...)
```

The list always consists of the samples added since last call to `InputSampler::get_samples()`.

All pointers are allocated with `new`, and it is the programmer's responsibility to free the allocated memory with `delete`. The functions have no reference to any memory location of objects returned.

In *Python*, things must be done differently. This is because of the difference in how *Python* and *C++* manage memory.

To facilitate computations, a *Python* class named `InputInterface` has been written. It has a constructor that sets up the lowlevel part of *Glisa*, and also converts *C++* arrays to *Python* numarrays. The data from the *C++* class `Sample`, will be converted to a equallent *Python Sample* class. All memory management that is needed, will also be taken care of by `InputInterface`, so the *Python* garbage collector will be able to reclaim memory allocated by the *C++* layer. See code listing 30.5.2

Code Listing 30.5.2 (Glisa initialisation)

```
import inputinterface

(...)

i = InputInterface()
samples = i.get_samples() \\samples is a Python list with
                          \\the Python class Sample.
smpl = samples.pop         \\Gets the first element in the list.
```

30.5.3 Implementation details

The lowlevel is divided in two, a device specific part, and a general part.

30.5.3.1 General part

The `Sample` class is a container class, which contains data from one sensor and one data glove. To maintain python compability, access methods are defined for datatypes that are not directly accessible in python, i.e. arrays. The class also has an ID of the glove/sensor pair whose data it contains, and a timestamp that specifics when the sample is made. Timestamp is of `double` type, where seconds is the whole part, and subseconds is the decimal part.

The `InputSampler` class contains methods for initializing the lowlevel system. When InputSample samples, it work on pairs. A pair consists of a data glove and a sensor controlled by the positioning device. When creating a pair, a data glove and a positioning device must already have been added.

When a data glove is added, an id is returned. If the adding fails, a exception of type `std::string` is thrown. The id of the glove must later be passed to the method that creates a pair. When adding a positioning device, the number of sensors is specified in an argument, the first sensor gets id 1 and so forth. Adding a positioning device may also create an exception of type `std::string`. To create a pair, one passes the glove id and the sensor id to the method `create_pair`. If there is a wish to create a pair consisting of only one glove, or only one sensor, -1 can be passed as id for the device not needed.

When pairs have been created, sampling is started with `initialize`. `initialize` takes one argument, the number of samples per second. `Initialize` creates a new thread, which is implemented as a POSIX thread, using the pthread library in C. The new thread enters a loop which samples from all pairs. Since only one thread is made, the maximum sampling rate will decrease linearly with the number of pairs, but for a small number of pairs, this is not a problem. When `initialize` is called, no further pairs, gloves or sensors can be added. The sampling thread polls all devices, and stores the result for each pair in a new instance of `Sample`. The new instance of `Sample`, is then added to a list, which is implemented as a class named `SampleList`.

The sampling thread can be terminated with `reset`. New pairs, gloves and sensors can then be

added, but reconfiguration of the old pairs is not possible. The sampling thread is restarted with `initialize`.

For an external class to gain access the samples, it must call the `get_samples` method. The method returns a object of type `SampleList`, which contains the method `get_next_sample`.

The `SampleList` class has a variable of type `std::list<Sample*>` which contains pointers to the samples. When a `get_list()` is called, a copy of the list variable is made and returned,and the original list is emptied. Since two threads may perform concurrent operations on the list variable, there is a need for some exclusion functionality. Mutal exclusions is implemented with a /textttpthread_mutex. All locks are released in the same function as they are set, so deadlocks is impossible.

The functionality of communicating with the positioning device is implemented through the class `PositioningDevice`, which is abstract. It is the base class of all implementations of positioning device drivers. This class specifies two functions, `get_data(int id, double posMatrix[4][4])` and `configure(string* ports, int no_of_ports, int no_of_objects)`. These functions give the position and orientation of an object in space, and configures the positioning device, respectively.

30.5.3.2 Device specific

The data gloves, are *5DT Data Glove 5*. A driver was provided, so to maintain generality, a wrapper class for the driver was implemented. `DataGlove` is the wrapper class between the *5DT Data Glove* driver and `InputSampler`. For the device specific positioning device functionality we have implemented a driver module for Ascension-Tech *Flock of Birds*, since the enclosed drivers were not compatible with the operating system on the Chemistry lab, Debian Unstable. In following sections, we will describe how this functionality is implemented.

The *Flock of Birds* driver module consists of two classes, `FlockOfBirds` and `SerialCom`. Inheriting `PositioningDevice`, the `FlockOfBirds` class makes up the interface for higher level software, i.e. `InputSampler`. It takes care of issuing the right commands to the *Flock of Birds* hardware using the functions in `SerialCom`. The use of these classes are described below.

The *Flock of Birds* device comes with one electronic unit for each sensor whose position and orientation can be measured. These units are referred to as bird units, one of which is the master of the *Flock of Birds* device. See the *Flock of Birds* section in the prestudy(section 16.3), or the *Flock of Birds* documentation [Cor02] for more details. To prepare a `FlockOfBirds` object for reading from the device one must call `configure(string* ports, int no_of_ports, int no_of_birds)`. This assumes that one is using a RS-232 interface to the master unit and the Fast Bird Bus(FBB) interface between the bird units, if more than one bird unit is used. Support for dedicated RS-232 interfaces to each bird is not implemented. The `configure` function auto-configures the hardware to have the given number of bird units, and sets the data record format of all bird units to be POSITION/MATRIX, meaning all bird units will represent their position and orientation in space by a 4x4 matrix.

Reading the position and orientation of a bird unit is done by calling `get_data(int birdAddress, double posMatrix[4][4])`, which takes a 4 by 4 matrix as an argument and fills it up so that it represents the sensor's position and orientation by a 4x4 transform matrix. This function uses `SerialCom` to issue a `RSTOFBB` command to the *Flock of Birds* device.This command tells the device

that the next command will go to the device with address birdAddress on the Fast Bird Bus.A `POINT` command is then issued, that makes the desired bird unit respond with its sensor's transform matrix. Bit shifting is then performed to convert the raw data from flock of birds, which is 14bits floating point numbers, to regular double presicion floating point numbers. If the bird's data record format is not set to POSITION/MATRIX, or something else is wrong, it will throw an exception in the form of a `<std::string>`.

The `SerialCom` class contains all the necessary functions for reading and writing to the serial port. To read and write from the serial port, make a `SerialCom` object with the `SerialCom(string portname)` constructor, call `open()` and then `read(char * data, int iLength)` and `write(char * data, int iLength)` as desired. `iLength` is the number of bytes to transmit, meaning `data` must be at least `iLength` bytes large.

Chapter 31

User Manuals

31.1 Installation manual

This will describe how to install *Glisa*

31.1.1 Dependencies and platform restrictions

31.1.1.1 Binary version

The binary version will install on a *Debian* 3.1 system. It is compiled for i686. It will probably work on other versions of *Debian*, but is not tested on other than version 3.1

The C++ binaries depend on:

- *GNU Standard C++ Library*
- *GNU Standard C library*
- *5DT Data Glove* driver
- *Python 2.3*

The first two libraries is installed on practically every *Linux* system. The third however, is a proprietary driver, and it must be installed on the system. The driver and installation manual for the driver can be found on *http://www.5dt.com/downloads.html*.

The *Python* part, depends on *Python* being installed.

31.1.1.2 Source version

The source version will work on a *Linux* computer who has the following dependencies met.

- *GNU Standard C Library* development files
- *GNU Standard C++ Library* development files
- *5DT Data Glove* driver and development files
- *GNU C* and *C++* compilers version 3.3 or higher(lower versions may work)
- *SWIG 1.3*
- *Python 2.3*
- *Python 2.3* deveopment files (package python2.3-dev in *Debian 3.1*

As for binary installation, the *5DT Data Glove* driver and development files, can be found at *http://www.5dt.com/downloads.html*. However, some versions of the driver will not link with newer versions of *GCC*. If there is problem with linking, please contact *5DT* to get a driver that will link with your version of *GCC*

31.1.2 Installation

31.1.2.1 Binary version

Glisa source is distributed as a *tar.gz* file, while the *Glisa* binary version is distributed as a *Debian* package. See code listing 31.1.1 for how to install.

Code Listing 31.1.1
```
$ cd <directory where the Glisa package is located>
$ dpkg -i glisa.deb
```

31.1.2.2 Source version

The source should be unpacked to the directory by running "`tar`" when in the directory where *Glisa* should be installed (see code listing 31.1.2). After unpacking, enter the subdirectory `lowlevel/input/c++code` and run "`make`" (see code listing 31.1.2).*Glisa* should now be ready properly.

Code Listing 31.1.2
```
$ tar xvfz <path_where_the_package_is_located>\glisa.tar.gz
$ cd  glisa/lowlevel/input/c++code
$ make
```

31.2 Demo application

This user manual describes how to use the demo application included with *Glisa*.

31.2.1 Introduction

The demo application was created to demonstrate the abilities of *Glisa*. The application intends to show how gloves can be used in a VR environment to interact with objects and control the scene. It is also a goal that other parts of the program, that is not displayed in 3D, can be controlled with a mouse. Before the gloves can be used in a 3D environment, they need to be calibrated, so the calibration application is started before the actual demo application displays. For information on how to use the calibration application, see section 31.3.

31.2.2 How to start

You can start the program by performing the following actions:

1. Make sure the *Flock of Birds* is powered.
2. Turn both birds on *Fly* at the same time. The light on the boxes should blink a couple of times.
3. Make sure the gloves are powered. A red light should be lit on the gloves if they have power.
4. Put on both gloves, and attach them properly.
5. Then start the program by running `./start` in the folder where *Glisa* was installed. For information on how to install *Glisa* see section 31.1.

31.2.3 The scene

After the calibration application has been run, a window will open and display the scene shown in figure 31.1. The 5 boxes are objects that can be selected and moved, and the two red pyramids indicate where your hands are located. If you move your hands you will see the pyramids move as well.

31.2.4 Manipulating objects

There are 5 cubes in different colors located in the scene. These objects can be selected or moved.

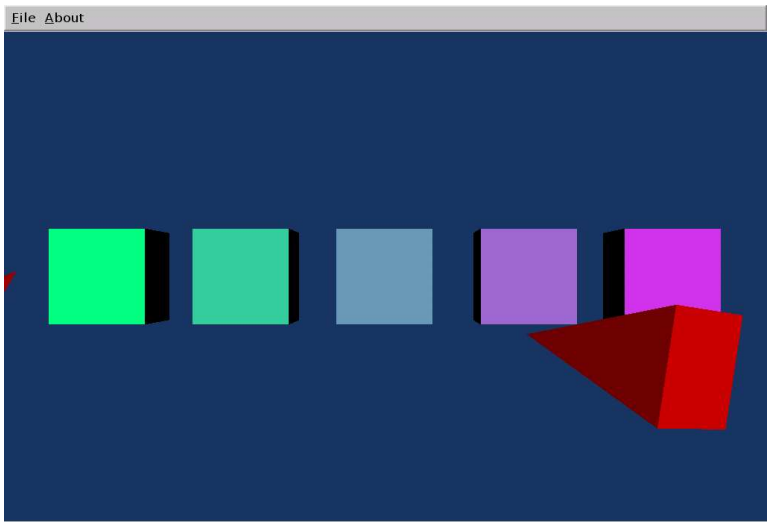

Figure 31.1: The scene that is displayed when the demo application starts

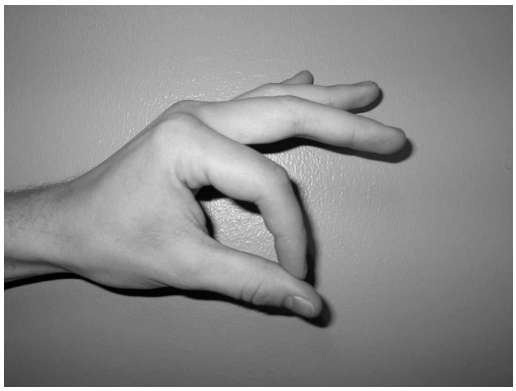

Figure 31.2: The pick posture

31.2.4.1 Selecting an object

To select an object do the following:

1. Move the hand indicator so that the tip of the pyramids are inside the object you want to select.

2. Then perform the pick posture as show in figure 31.2. If the pick was successful, the object will turn yellow.

31.2.4.2 Selecting several objects at the same time

Several objects can be performed at the same time by creating a selection box around the objects you would like to select. This is done in the following way:

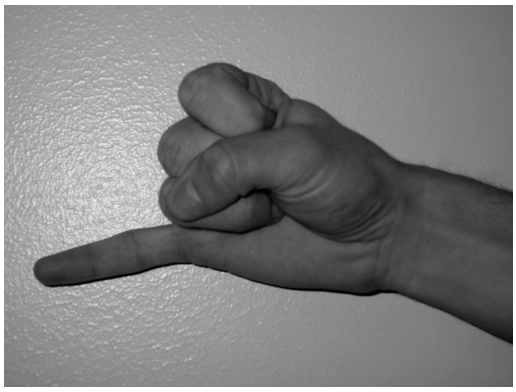

Figure 31.3: The selection box posture

1. Perform the selection box posture shown in figure 31.3 with both hands. A selection box should appear between the two pointer indicators.
2. Move your hands so that the selection box surrounds the objects you would like to select. Notice that each hand controls the position of two opposite corners in the selection box.
3. The actual selection is done when the posture is released. Only objects with its center within the selection box when the posture is released will be selected.

31.2.4.3 Moving and rotation an object

It is also possible to move or rotate objects. To accomplish this do:

1. Move the pointer indicator inside the object you would like to move or rotate.
2. Perform the grab posture as show in figure 31.4. You will see when you've managed to grab an object when it sticks to the pointer.
3. To move the object, just move your hand, and to rotate the object, rotate your hand.
4. When you are done manipulating the object, open your hand and the object will be released.

31.2.5 Navigating in the scene

It is possible to rotate the view of the scene. In the scene, there is defined an invisible origin in the center of the scene. Navigation in this application is defined as controlling from which angle the user looks at this origin. This can be achieved by following this procedure:

1. Perform the posture shown in figure 31.5 to enter navigation mode. Only the right hand can be used to enter navigation mode.

Figure 31.4: The grab posture

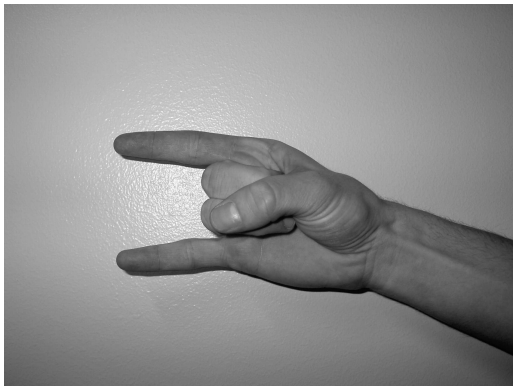

Figure 31.5: The navigation mode posture

2. When in navigation mode, you can rotate the view to the right by moving your hand to the right, and likewise rotate the view to the left by moving your hand to the left. If you move your hand upwards when in navigation mode, the view will rotate upwards, and the a downward movement will rotate the view downwards.

3. To stop navigating, release the posture.

4. To move the view back to its starting position, a gesture can be performed. The gesture is performed by first doing the gesture posture, and then moving the hand along a L-shaped pattern in front of you, before releasing the posture. For more information on how to perform gestures see section 31.4.

31.2.6 Using the gloves to control the mouse

The right glove can be used to control the mouse. The steps to do this are as follows:

1. To start moving the mouse, you must first enter 2D mode by performing the posture shown in figure 31.6. After this posture has been performed, the red pyramids in the scene will no longer track the movement of your hands. Instead the normal mouse pointer will track the movement of your right hand.

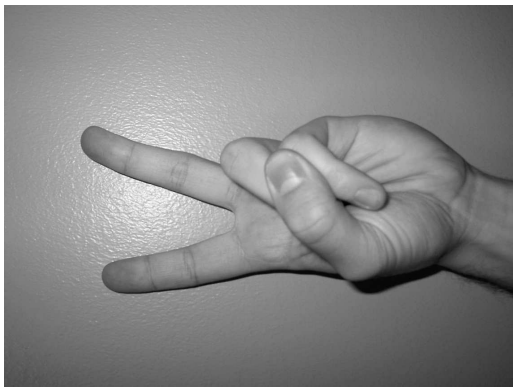

Figure 31.6: Posture for entering 2D mode

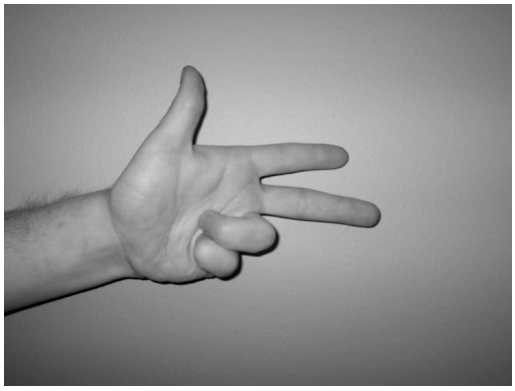

Figure 31.7: Posture for entering 3D mode

2. When in 2D mode you can use the right glove as a normal mouse. Left clicking is done by flexing and extending your index finger. If you want to hold the left mouse button, just flex the finger without extending it again. The right button can be clicked by extending and releasing your thumb in the same way.

3. If you want to go back into 3D mode, you must perform the posture showed in figure 31.7.

31.2.7 Closing the demo application

The demo application can be closed either by clicking on the X in the top right corner, or by choosing "Exit" from the "File" menu.

31.3 Calibration Application

This is the user manual for the calibration application of *Glisa*.

31.3.1 Introduction

The calibration application is a support application used to create a mapping between the virtual and physical space. This is needed for an application using gloves to decide where exactly the user tries to perform an action.

31.3.2 Using the calibration application

When starting the application the user will be presented the text *"Start Grabbing"*, as illustrated in figure 31.8. After four seconds this command will be substituted by the command *"Stop Grabbing"*, lasting for additional three seconds, as illustrated in figure 31.9. During these 7 seconds the user must flex and extend all fingers several times, in order to calibrate the gloves. This must be done for the rest of the calibration to execute properly.

Figure 31.8: Screenshot when the command "Start Grabbing" is displayed

Figure 31.9: Screenshot when the command "Stop Grabbing" is displayed

The next screen presented to the user will display eight cubes, one in each corner of a larger imaginary cube, as illustrated in figure 31.11. Each box is to be picked by the user as described later in this paragraph, see figure 31.10. The physical space spanned by the eight picks of the user, constitutes the space in which the gloves are in a calibrated state. When using the gloves in a main application,

all actions should therefore preferably be performed within this space. One of the cubes displayed is highlighted. The user should pick the highlighted cube using the right hand glove. Once the cube is picked, another cube will be highlighted. This procedure should be performed for all eight cubes. When the last cube is picked, the calibration is complete. If several cubes are picked simultaneously during a single pick, the actions *"Start Grabbing"* and *"Stop Grabbing"* have not been performed correctly. The calibration application should then be restarted.

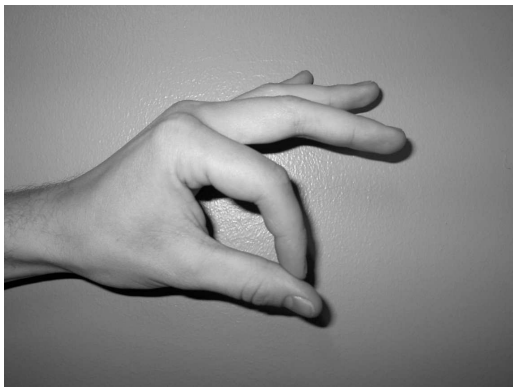

Figure 31.10: The posture for picking a cube

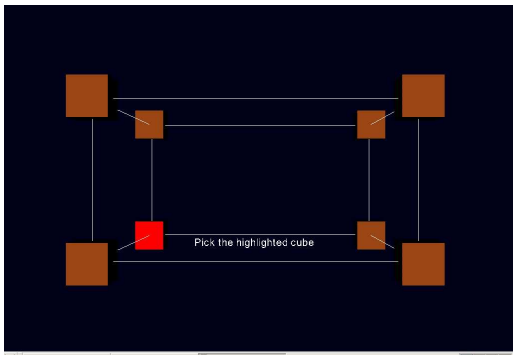

Figure 31.11: Screenshot when the eight cubes are displayed

31.4 User manual for gesture training application

This is the user manual for the gesture training application of *Glisa*.

31.4.1 Introduction

The gesture training application is an application developed for training and testing of gestures. A gesture is a movement pattern carried out with either hand. In our system we have defined a gesture to happen when the user stretches out the thumb and flexes the other fingers as shown in figure 31.12. While keeping the hand in this way the user should carry out the gesture and when done flex the thumb and/or extend the other fingers to indicate that the gesture is done.

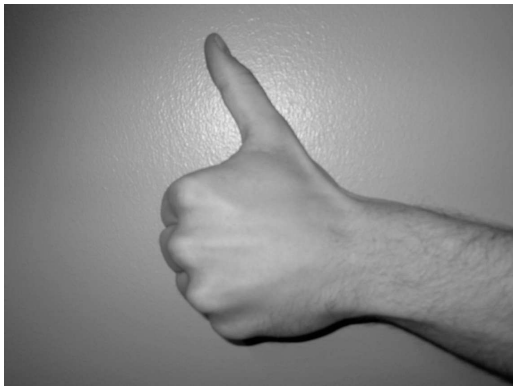

Figure 31.12: This is the hand posture for performing a gesture.

Recognizing a gesture is computationally heavy and it is difficult to get the recognition rate of a gesture sufficiently high. Therefore the user have to train a gesture before it can be used. The more times a gesture is trained the better the recognition rate.

In addition to training of new gestures the application provides support for looking up, editing, deleting and testing already existing gestures. The startup window of the gesture training application is shown in figure 21.7. This user manual will stepwise guide you through these features. The manual is split into three main parts, as is the application, which is adding a new gesture, testing a gesture and looking up available gestures.

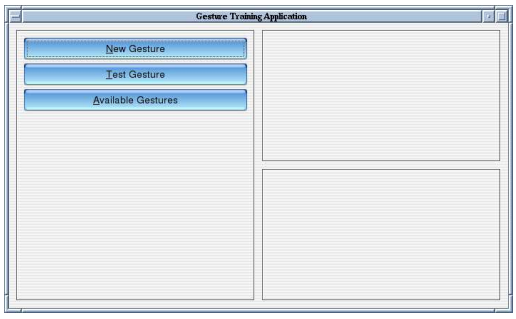

Figure 31.13: A screenshot of the window appearing when starting up the gesture training application.

31.4.2 Start program

The program is started by typing `./training` when in the directory /etc/source.

31.4.3 Add a new gesture

A stepwise guide for adding a new gesture into the system:

1. To add a new gesture into the system press the *New Gesture* button in the startup window. The window shown in figure 31.14 will appear.
2. Type in the name of the gesture in the edit line under *Gesture name* and type in a short description of the gesture in the edit line under *Description of Gesture*. Example: Gesture name: *Circle* Description of Gesture: Counter clockwise circle.
3. Press the *Perform Gesture* button. This is when you actually start training the gesture. Perform the gesture a sufficient number of times (15-100). You do not have to press *Perform Gesture* or *Done* each time. The counter next to the *Perform Gesture* button displays the number of times you have performed the gesture. Additional feedback is given through the light in the bottom left corner of the application, which is set green when a gesture is being performed and red when not.
4. When done training press the *Done* button. The new gesture is then added to the system.

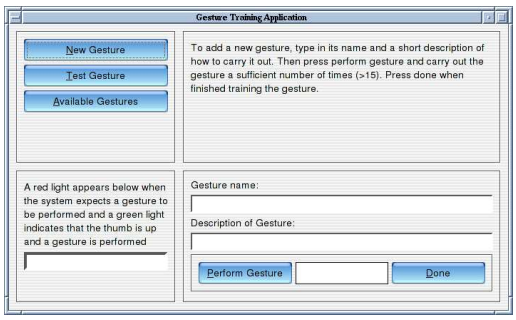
Gesture Training Application
New Gesture
Test Gesture
Available Gestures
To add a new gesture, type in its name and a short description of how to carry it out. Then press perform gesture and carry out the gesture a sufficient number of times (>15). Press done when finished training the gesture.
A red light appears below when the system expects a gesture to be performed and a green light indicates that the thumb is up and a gesture is performed
Gesture name:
Description of Gesture:
Perform Gesture
Done

Figure 31.14: A screenshot of the window appearing when the *New Gesture* button is clicked.

31.4.4 Look up available gestures

To look up existing gestures, edit a gesture or delete a gesture do the following:

1. To look up available gestures, simply press the *Available Gesture* button in the start up window. All available gestures are then listed in the table that appears. The window is shown in figure 31.15.

2. To edit a gesture, double click the cell in the table you want to edit and do necessary changes, then press enter to go out of the cell. When you are finished editing press the *Save changes* button.

3. To delete a gesture write its name in the edit field next to the delete button and press delete. The gesture is then deleted from the system.

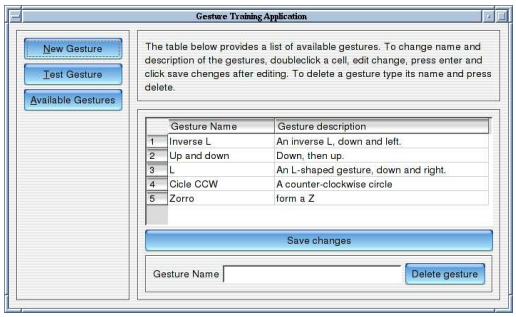
Gesture Training Application
New Gesture
Test Gesture
Available Gestures
The table below provides a list of available gestures. To change name and description of the gestures, doubleclick a cell, edit change, press enter and click save chenges after editing. To delete a gesture type its name and press delete.
Gesture Name
Gesture description
1 Inverse L An inverse L, down and left.
2 Up and down Down, then up.
3 L An L-shaped gesture, down and right.
4 Cicle CCW A counter-clockwise circle
5 Zorro form a Z
Save changes
Gesture Name
Delete gesture

Figure 31.15: A screenshot of the window appearing when the *Available Gestures* button is clicked.

31.4.5 Test an existing gesture

Testing of an existing gesture means that you try to perform one or more of the existing gesture in order to find out if you are doing them right and learn how to perform them to get the recognition rate high. A stepwise guide for testing a gesture:

1. To test an existing gesture press the *Test Gesture* button in the startup window. The window shown in figure 31.16 will appear.

2. Press the *Test* button, which activates the testing. Then perform the gesture(s) you want to test out.

3. If the gesture you are performing is recognized the name of the gesture and the recognition probability is displayed in the text fields under *Gesture name* and *Recognition certainty of the tested gesture*.

4. You may test as many gestures as many times as you want, but when finished testing press the *Done* button.

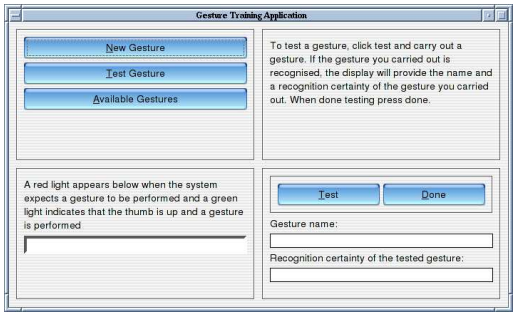
Gesture Training Application
New Gesture
Test Gesture
Available Gestures
To test a gesture, click test and carry out a gesture. If the gesture you carried out is recognised, the display will provide the name and a recognition certainty of the gesture you carried out. When done testing press done.
A red light appears below when the system expects a gesture to be performed and a green light indicates that the thumb is up and a gesture is performed
Test
Done
Gesture name:
Recognition certainty of the tested gesture:

Figure 31.16: A screenshot of the window appearing when the *Test Gesture* button is clicked

Chapter 32

Coding guidelines

This chapter describes guidelines related to how source code is to be written. It is, however, not to be regarded as rules that has to be followed The only absolute rule is that the source code should be as readable as possible to a person that is used to the conventions described here. If a guideline results in code that is unintuitive or hard to read, it is the programmer's responsibility to decide that the guideline does not apply.

Some general conventions apply:

- When code is not finished at the time of writing, a todo-comment must be created. This comment shall start with the text `TODO:` , that is the word "todo" in uppercase followed by a colon and one space. After the colon, the remaining work is described in sufficient detail so that another programmer could finish the implementation.

- Known bugs are indicated by a comment, `FIXME:` , that is the word "fixme" in uppercase followed by a colon and a space. After the colon, the problem must be described.

- No temporary solutions ("hacks") are allowed at any time of writing, because these have a tendency to live on to the finished product, decreasing the quality of the product. This is not meant to forbid "stub" implementations, where some functionality is hard-coded or not coded at all to make other parts of the program testable.

- Undocumented code is not finished, and is not allowed to be part of a release to the customer. The same applies to code that is not covered by an automated unit test.

- Unit test code is not under the same documentation requirements as the code of the library (which means that documentation standards may be loosened, and that documentation for cases that are *undoubtly* trivial may be omitted).

- No line of code may be longer than 78 columns.

32.1 Python code

It is an external requirement from the customer that all python source code follow the conventions in PEP 08, a document available from the Python Software Foundation concerning source code standards. In addition, all code should be properly documented according to PEP 257, a standard for writing documentation in python code.

An example of a module following these conventions is given in code listing 32.1.1.

Code Listing 32.1.1 (PEP 08-compliant python code example)

```
"""Simple counter module.

This module contains both a class for a bi-directional counter, Counter, and
a generator function returning a function that increments its argument by a
given amount.

class Counter: A simple counter.
function incrementor(amount): Creates an incrementor-function.
"""

__revision__ = 1


class Counter:
    """Simple counter class.

    This class is simply counting up and down, keeping track of the value.

    Data:
      _value: Current value of counter. Not to be accessed from the outside.
    Methods:
      __init__([init_value=1]): Initialize the counter.
      inc([amount=1]): Increment the counter.
      dec([amount=1]): Decrement the counter.
      get_value(): Return the value of the counter.
    """

    def __init__(self, init_value=1):
        """Initialize the counter with an initial value."""
        self._value = init_value

    def inc(self, amount=1):
        """Increment this counter by a given amount."""
        self._value += abs(amount)

    def dec(self, amount=1):
        """Decrement this counter by a given amount."""
        self._value -= abs(amount)

    def get_value(self):
        """Get the value of this counter."""
        return self._value


def incrementor(amount):
    """Return a function incrementing it's argument by amount."""
    return lambda(a): a+amount
```

32.2 C/C++ code

C and C++-code is expected to adhere to the conventions described in this section. An example is shown in code listing 32.2.1. Indentation policies can be enforced by using the tool "Artistic style", invoked as `astyle -style=ansi file.cpp` to pretty-print the file `file.cpp`.

The conventions for C/C++ code are:

- The indentation length is 2 spaces. No tab characters are allowed (this has to be set in the editor settings).
- All opening/closing braces (i.e. { and }) should be on a line of their own.
- Opening parentheses after a language construct (if, for, while, etc.) is preceded by a space, while opening parentheses after a function call (like "bar();") is not.
- One-line blocks (like the else-branch in the example, code listing 32.2.1) are not enclosed in braces.
- Names and style of documentation should conform to the standard for Python code, for consistency. Leading underscores in private member names are omitted (since C++ has support for visibility).
- Public classes are defined in a header file with the same name as the class, and implemented in a corresponding file with suffix *cpp*. All file names are lowercase, according to the guidelines in the project directive.
- All functions, global variables, classes and class members are documented with a documentation comment suitable for *doxygen* (following *javadoc* syntax). For class members, the documentation is written in the class definition in the header file, not in the implementation of the member function itself.
- As far as possible, Standard Template Library (STL) constructs should be used instead of classic C types (e.g. use `vector<int>` instead of `int*` and `string` instead of `char*`).

Code Listing 32.2.1 (C++ style example)

```
namespace foospace
{
  /**
   * Simple counter class.
   *
   * TODO: This class is not fully implemented, functions for incrementation
   *       and decrementation, and for access to the counter's value, are
   *       missing.
   */
  class MyCounter : public YourCounter
  {
    protected:
      /** Counter value. */
      int value;
    public:
      /** Initialise the counter with a default value.
       *
       * @param value Initial value for this counter.
       */
      MyCounter(int initial_value=1);
  }

  MyCounter::MyCounter(int initial_value)
  {
      value = initial_value;
  }

  /**
   * Go bar() if there is a bar nearby, until you are fubar.
   *
   * @return Returns 1 if there was a bar, 0 otherwise.
   */
  int foo()
  {
      if (isBar)
      {
       bar();
       return 1;
      }
      else
        return 0;
  }
}
```

Part VI

Test Documentation

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Chapter 33

Introduction

This is the test document of group 11 in the course *TDT4290 Customer driven project*. This document is intended to provide a detailed description of the different tests for the Glisa system along with the test results. These tests are very important to analyse all parts of the system, ranging from system specific faults to the actual usability of the system. Another important part covered by the tests is to ensure that the system fulfills the requirement specification satisfactory. Four main tests of *Glisa* are planned, namely module tests, system test, acceptance test and usability test.

The test document is divided into the following succeeding chapters:

- Chapter 34 - Module test, which describes unit and module testing of *Glisa*.
- Chapter 35 - System test, which describes the system test of *Glisa*.
- Chapter 36 - Acceptance test, which describes the acceptance test of *Glisa*.
- Chapter 37 - Usability test, which provides a description of the usability test. The test itself is included as an appendix.

Chapter 34

Unit and module tests

This chapter describes the unit and module testing related to *Glisa*. Unit testing is the testing of individual modules, preferably automated, while module testing means integrating separate units into modules and testing these units as a whole. *Glisa* is separated between the support applications, applications, middleware module and lowlevel module, and these will be tested separately in the module tests, where automated testing is possible.

34.1 Low-level drivers

34.1.1 Unit test for lowlevel

The lowlevel consists of a small set of classes and methods, so unit testing has been performed pseudoautomaticly, i.e. by the help of small functions that tests methods on correct inputs, as well as inputs that will generate an error. Testing has been performed by covering the range of input, and printing the output values.

Specifically, we have tested the *Flock of Birds* driver by the aid of a simple reading test class, written in C++. This class simply instantiates a `FlockOfBirds` object and configures it to use two sensors, attached to the serial port. It has a function for reading the position and orientation for a given bird. The test program uses this class to prompt for a number, 1 or 2, specifying which bird to read from. This is done repeatedly until the user hits a special key for exiting the program.

34.1.2 Module test for lowlevel

The module test for lowlevel was carried out using simple C++ programs that did what the tests wanted. Result of the test is shown in table 34.1. Example of a program is shown in code listing 34.1.1.

Code Listing 34.1.1

```
#include "input_sampler.h"
#include <iostream>

int main(int argn, char** argv)
{
  InputSampler i = new InputSampler();
  try
  {
    add_glove("/dev/ttyS0");
  }
  catch(string s)
  {
    cout << "add_glove feilet: " << s;
  }
  try
  {
    i.add_positioning_device("/dev/ttyS1");
  }
  catch(string s)
  {
    cout << "add_positioning_device feilet: " << s;
  }
}
```

34.2 Middleware

All classes in the middleware are covered by automatic unit tests (except for the Hidden Markov Model recogniser machine learning functionality), written using the python `unittest` module. These tests do not adhere to the coding conventions, as the `unittest` module does not.

The middleware module test is covered by an automatic test that developers commit to run whenever altering the source code. It consists of the following tests:

1. Addition of an event listener to the 3D Input Device handler, `Input3D` and reception of events over the `Input3DListener` interface. This is covered by the unit test for the `control` module.

2. Addition of an event listener to the abstract gesture recogniser and reception of `GestureEvents` given that the gesture recogniser acts in accordance with the specification. This is realised through the unit test for the `gestrec` module.

3. Changing between 3D Input Device and Mouse Emulation modes. This is covered by the unit test for the `control` module.

4. Reading of configuration for the entire system through XML. This is realised in the unit test for the `control` module.

Test case:	1	
Purpose:	To test if we get the desired output from the lowlevel. Will test the data flow in the lowlevel	
Tool used:	Lowlevel layer with extended use of output	
Test number	**Description**	**Results**
1	Add a glove that is connected	OK. Test failed from time to time, but the problem was located to be in the *Linux* kernel module for an USB to serial converter, and after an upgrade to the 2.6 kernel series, everything works well.
2	Add a glove that is not connected	OK. Gets an exception, which is catched.
3	Add a positioning device	OK.
3	Add a positioning device not connected	OK. Gets an exception.
4	Read data from glove.	OK.
5	Read data from bird.	OK.
6	Try to access out-of-range values for finger flexure and position coordinates in the Sample class.	OK. Don't get error, but 0, which is expected.
7	Check timestamps in Sample class	OK.
8	Do a continuous loop for one minute to check if the sampling thread stays alive.	OK.
8	Run *Valgrind* (See section 28.4.2) to check for memory leaks	OK.

Table 34.1: Test case 1 in the lowlevel module test

All automatic tests for the middleware (and the python interface to lowlevel auto-generated wrapper) are independent of the low-level drivers and the presence of hardware. Fake samples are returned through interfaces acting in conformance to the specifications.

34.3 Applications and support applications

The graphical applications have not been subject to automated unit testing, but during development, the gesture training application has been tested with samples collected from previous runs, thus coming close to a module test requiring of the middleware and the gesture training application.

Chapter 35

System test

This chapter describes the system test for *Glisa*.

35.1 Goal

The purpose of the system test is to determine if the product meets the requirements specified in the requirements specification. The demo application is meant to show the functionality in *Glisa*, and by doing so, it actually functions as a test of the middleware requirements. The system test should therefore concentrate on testing the application requirements, and also ensure that all middleware requirements are tested by the demo application or by other means. Errors discovered in the system test must either be fixed before the product is delivered, or noted on the list of work that needs to be done by the customer. These lists are located at the end of section 35.3.

35.2 Test specification

Table 35.1 lists the requirements from the requirements specification and a remark on if the requirement must be tested by the system test, or if it is tested through another requirement. The demo application does not test all functionality in *Glisa*, but these requirements are tested by the automatic unit tests (requirement NFMA-3) or one of the support applications (requirements SA-1 and SA-2).

The system test is divided into several test cases, where each case tests one or more of the requirements listed in table 35.1. We have defined the test cases listed in table 35.2 through 35.6, with the specified requirements as test targets.

ID	Tested by
SA-1	System test – Demo application and gesture training application
SA-2	System test – Gesture training application
A-1	System test – Demo application
A-2	System test – Demo application
A-3	System test – Demo application
A-4	System test – Demo application
A-5	System test – Demo application
A-6	System test – Demo application
A-7	System test – Demo application
A-8	System test – Demo application
A-9	System test – Demo application
A-10	System test – Demo application
A-11	System test – Demo application
A-12	System test – Demo application
M-1	Tested in conjunction with requirements A-1 through A-12
M-2	Automatic unit test of module `control`
M-3	System test – Gesture training application
M-4	Tested in conjunction with requirement A-6
M-5	Tested in conjunction with requirement A-6
M-6	System test – Demo application
M-7	Tested in conjunction with requirement A-7
M-8	Tested in conjunction with requirement A-10
M-9	Automatic unit test of module `input3d`
M-10	Tested in conjunction with requirements A-3, A-4 and A-5
M-11	Automatic unit test of module `control`
M-12	Tested in conjunction with requirement A-7

Table 35.1: How the requirements are tested

35.3 Conclusion

Of the 20 tests in the five different test cases given in section 35.2, 18 were successful, and two failed. The two failing tests were the second last test in test case one, right clicking the mouse in mouse emulation mode, and the first test in test case five, performing built-in gestures with a minimum recognition rate of 80%. The reasons to why they failed is a poorly adjusted posture and too ambitious regarding the gesture recognition rate, respectively. This means that with the exception of requirement M-4 and A-4, all requirements are met at the time the system test was performed. Requirements M-4 is partly met except for the gesture given in figure 21.17, which turned out to be very difficult to recognise. The postures given by requirements A-9 and A-10 in section 21.1 in the requirements specification, have been changed because they turned out to be difficult to perform and/or recognise. This is further elaborated in section 30.1.

We have created two list of things to be done based on the result of the system test. The first list contains what is possible for us to fix before handing in the product:

- Adjust the thresholds for the postures for creating a selection box. (Fixed)

Test case:	1	
Purpose:	To test if mouse emulation works	
Tool used:	Demo application	
Requirement	**Description**	**Results**
A-1	The user should be able to enter 2D mode by performing a posture.	OK. Returned to 3D-mode by accident.
A-5	The mouse pointer should track the movement of the hand.	OK.
A-3	The user should be able to left click the mouse by flexing the index finger.	OK. The glove must be properly worn and all straps must be properly tightened or else the operation will be difficult to perform.
A-4	The user should be able to right click the mouse by flexing the thumb.	Not OK.
A-2	The user should be able to enter 3D mode by performing a posture.	OK.

Table 35.2: Test case 1 in the system test

The other list contains what the *SciCraft* developers could be interested in fixing after the product is handed in:

- Move the *flock of birds* sensor to one of the fingertips in order to track the position at the fingertips. Another possibility would be to set an offset to compensate for the distance from the sensors to the fingertips.
- Improve the system for gesture recognition to obtain a higher recognition rate.
- Replace the partly defect right hand glove.

Test case:	2	
Purpose:	To test if the gloves can be used to manipulate objects in a virtual environment	
Tool used:	Demo application	
Requirement	**Description**	**Results**
A-7	Graphical pointer devices should track movement of the hands.	OK. Tracks the position of the sensors, not the fingertips.
A-8	If a selection posture is a performed with a hand, and the pointer indicator belonging to that hand is inside an object, that object must be selected.	OK. It is possible to select rotated objects without having the pointer inside it because the system uses an axes-parallel bounding box to test if a box is to be selected.
A-8	The user should be able to change the selection by picking another object. The previously selected object should be deselected.	OK.
A-9	If the user extends both index finger, and lets the finger tips connect, a selection box should be created	OK. The implemented posture was i little hard to perform.
A-9	When the user moves his hands apart, the selection box should b e expanded.	OK.
A-9	When the user flexes both index fingers, all objects within that box are selected. Any object previously selected that are not within the box must be deselected.	OK.
A-10 and A-11	The user should perform a grab posture on a selected object. When this is done the object should move together with the pointer indicator when the hand is moved. When the user releases the posture, the object should stop moving.	OK for the right hand glove. Hard to do with the left hand glove because of loose sensors giving partly corrupted data.

Table 35.3: Test case 2 in the system test

Test case:	3	
Purpose:	To test if the gloves can be used to navigate in a virtual environment	
Tool used:	Demo application	
Requirement	**Description**	**Results**
A-12	When the user does the navigation posture, the system should enter navigation mode. In this mode the pointer indicators should no longer track the movement of the hands.	OK for the right hand glove, not for the left.
A-12	When in navigation mode, the user camera should track the movement of the hand that performed the navigation posture.	OK for the right hand glove, not for the left, as a result of the outcome of the previous test.
A-12	When the user releases the navigation posture, the system should go out of navigation mode, and pointer movement should work as normal	OK.

Table 35.4: Test case 3 in the system test

Test case:	4	
Purpose:	To test if the system is able to recognise gestures	
Tool used:	Demo application	
Requirement	**Description**	**Results**
A-6	If the user performs a gesture the program should perform the expected action.	OK.

Table 35.5: Test case 4 in the system test

Test case:	5	
Purpose:	To test the gesture training application	
Tool used:	Gesture training application	
Requirement	**Description**	**Results**
M-6, M-4	The user should be able to enter testing mode by clicking "Test Gesture" and then "Test". In testing mode, the gesture training application should in 80% of the cases indicate which gesture has been performed when the user has performed a gesture, if the gesture exists and only the gestures defined in the requirements specification are defined in the database, with a maximum training set of 40 repetitions. The built in gestures in requirement M-4 illustrated in figures 21.15, 21.16,21.17 and 21.18 from section 21.3 in the requirements specification are called *L*, *inverse L*, *circle* and *up&down*, respectively.	Performed each gesture 10 times. The right hand glove had the following results: • : *L*: 60% recognition rate. • *inverse L*: 80% recognition rate. • *Up&Down*: 80% recognition rate. The gesture *circle* turned out to be too difficult to recognise. It also works using the right hand glove, but testing with it was difficult because it has loose sensors giving partly corrupted data.
SA-1	The user should be able to train a new gesture by clicking the "New Gesture" button, typing in its name and description, and then click the "Perform Gesture" button and perform the gesture. When no more than 40 samples of the gesture has been demonstrated indicating each repetition with the relevant posture, the "Done" button must be clicked.	OK.
SA-1	The newly trained gesture should then appear on the list of available gestures accessible by clicking the "Available Gestures" button.	OK
M-6	After training, the user should be able to enter testing mode, and the system should recognise the newly trained gesture.	Works for simple gestures, but not for very complicated gestures.

Table 35.6: Test case 5 in the system test

Chapter 36

Acceptance test

36.1 Acceptance Test - results and errors

This sections describes the acceptance test for the whole system. The results is shown in table 36.2.

36.1.1 What to test

The test will be performed by the client. Since the main purpose of *Glisa* is to provide an API for a programmer, much can not be tested in a reasonably amount of time. The test therefore concentrates of the GUI part, i.e. DemoApplication and the GestureTrainingApplication.

Test type:	Acceptance test
Purpose of the test:	To test how *Glisa* function according to the clients expectations
Time estimated:	40min
Time used:	30min
Client name:	Bjørn K. Alsberg
Testleaders name:	Frode Ingebrigtsen
Comments:	Due to the nature of *Glisa*, an intuitive GUI is not a prioritized task, so the customer is allowed to request help for postures, how to train a gesture, and how to start the application.

Table 36.1: Test type

36.1.2 Results

The customer accepts the product. Some remark was made of choices of postures and gestures, but *Glisa* is easy configurable, so some editing of an XML file is sufficient to change postures. Gestures can be changed in the gesture training application. The customer may redefine all postures and gestures to match own need later.

Number	Subject to test	Expected result	Actual result	Approved
1	Start Demo application	DemoApplication should be started, and calibration should be performed	The DemoApplication started, and calibration succeeded	OK
2	Pick an object	The object picked should be highlighted	The object got a highlight	OK
3	Grab and move an object	The object grabbed should be moved and rotated according to the movement of the hand.	The object got grabbed, and moved followed the hand movement	OK
4	Rotate the coordinate system	The client should be able to rotate the coordinate system	The coordinate system rotated	OK
5	Train a gesture	The client should be able to start the gesture training application and make a new gesture that should be recognized.	The client trained a gesture, and it was recognized	OK
6	Enter 2D mode	The client should be able to control the mouse pointer with the mouse, and use a posture to click	The client had some problems with the posture, due to a posture that was hard for the client to perform. But after some try and fails, the client succeeded.	OK
7	Perform a gesture inside the Demo application	A gesture should be recognized.	The gesture got recognized	OK
8	Select objects with a selection box	The objects selected should be highlighted	The selected got highlighted	OK

Table 36.2: Acceptance test

Chapter 37

Usability test

37.1 Goal

The goal of this test is to determine if *Glisa* is successful in making users feel comfortable using the HCI devices in a virtual environment. Since this test will be performed with the end product, we do not expect to be able to do any major modifications on *Glisa* based on this test. The test results should rather be used to determine the possible problems and work that needs to be done on *Glisa* after the final delivery. However, minor GUI changes can be done in accordance with feedback from the test persons. The rest should be document well for further development.

37.2 Time and place

The test is to be performed November 16^th.For optimal results the usability test should be carried out with about seven persons. Because of availability issues of other people we plan to do this test with three persons, which will give us a fairly good indication of the system availability. We estimate the user to spend approximately 45 minutes each on the test, making up a total of about two and a half hours for executing the entire test. As the test needs the setup with projectors mounted in stereo and the *Flock of Birds*, we will have to use the 3D lab at the Institute of Chemometrics to carry out this test.

37.3 Setup

The following equipment will be needed in the 3D lab for the execution of this test:

- Canvas.
- Projectors mounted in stereo.

- One pair of *5DT DataGloves 5*.
- *Flock of Birds* with two sensors attached one on each hand.
- One computer that all the other devices must be connected to.

In addition the following software must be installed on the computer:

- Debian Unstable
- VTK and Qt
- Drivers for *5DT DataGlove 5* and*Flock of Birds*
- *Glisa*
- The demo application with all modules needed.

37.4 Roles

Test person

The test person should wear gloves with the sensor attached, and stand in front of the canvas. The person must be someone outside the project team, but could very well be one working for the customer. For the test to give reliable results, a number between 7 and 10 different test persons should be used.

Test leader

This person will do all the presentation of the testing equipment, people present under the test and the test itself. He should assure that before the test starts he briefs the test person with the following 9 topics:

1. Introduce yourself and any other people in the room.
2. Describe the purpose of the test.
3. Explain that the test person can abort a given task at any time, and may also stop the test at will.
4. Teach how to to think loudly, that is to say what you think while the test is performed.
5. Explain that neither you or the other persons in the room can offer assistance with the test.
6. Introduce *Glisa* and the demo application to be tested.
7. Ask the test person if he/her has any uncertainties and run the test.

After the test, thank the test person for his/her participation and let the test person comment on any issues he/she encountered during the test.

During the actual test, the test leader should read out tasks for the test person to perform with the demo application and gesture training application.

Observators

At least 2 observators should participate in the test to ensure that all results are noted. They should take care to note whenever the test person seems uncertain of what to do, fails in a task or does anything else that could indicate a problem with the program.

37.5 Test tasks

During the test, the test person should be given clearly defined tasks to be executed one at a time. These tasks must be formulated in such a way that they do not indicate any solution to the task, but must be specific enough so that the test person is certain of what he/she is supposed to achieve. The tasks must be written after the product is finished so that they can be tailored to the actual functions presented in the applications. The tasks of the usability test are provided in appendix K. Short notes from the results are also written beside the task and expected result, while the conclusion below sums up the results.

37.6 Conclusion

This conclusion is divided into three parts, one for each tested application, namely the calibration application, the gesture training application and the demo application.

37.6.1 Calibration application

If the user does not calibrate the glove by grabbing when start grabbing is displayed, the selection of cube corners afterwards becomes difficult. It is a bit difficult for the user to know the degree of grabbing during this session, but this is a matter of training and getting comfortable with the equipment. It is a bit difficult to handle the gloves perfect the first time.

The matter of selecting the highlighted corner of the cube was very intuitive and everyone got that right.

37.6.2 Gesture training application

The main problem with this application was the fact that none read the description that was provided in the GUI. All the tasks are explained quite clearly there, but the text was maybe to long. Thereby some people struggled to perform some of the functionality at first.

For example the most intuitive way of deleting a gesture would be to select it and then press delete. Therefore one test person did this rather than writing its name in the edit field and press delete. This is because that is maybe the most standard way to do it and should be considered a subject for future improvement. The text field for writing the name for the gesture you want to delete was actually confusing for one of the test persons.

The same problems goes for editing a gesture. The fact that you have to press enter to deactivate the cell before pressing save changes was not very intuitive and should be changed in future versions. Other than these issues the application worked well seen from a usability point of view and everyone seemed to enjoy the feedback given on whether a gesture was being performed or not.

37.6.3 Demo application

The postures for selecting and grabbing and partly the posture for 2D and 3D mode of boxes were very intuitive to all users. The other postures did not bear the same level of intuitiveness, because of limited functionality of the data gloves, but once we explained them to the user they managed to use them. The exception was the posture for selecting several boxes, which hardly any of the test persons managed to do properly. The rotation could also have been solved differently. Rather than changing the camera position, the actual object(s) should have rotated.

Part VII

Evaluation

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Chapter 38

Introduction

At the end of the project, we performed an evaluation to better understand the process we have been through. Positive and negative sides of both the process and the project as a whole was taken into consideration. The evaluation method used is called post mortem analysis.

In the first phase of the evaluation each group member wrote down five comments on what they believed could have been better during the process. All comments where categorised into groups. The three groups considered to be most important were prioritised order considered to be:

1. Time
2. Design
3. Requirements

For each of these groups there was made an Ishikawa diagram on a white-board, with reasons to why they were not as good as they could have been. These diagrams are not included in this evaluation document, since they were wiped out as the process proceeded. A picture from this process is shown in figure 38.1 Each group of discussion is elaborated further in section 39.

The second phase was a repetition of the first, only from a different point view. Comments written in this phase was to be about good sides about the process, or positive things with the project. The three groups considered to be most important were prioritised order considered to be:

1. Documentation
2. Cooperation
3. Retrieved knowledge

These groups are also further elaborated in section39. This concluded the evaluation session.

Figure 38.1: Tutor Finn Olav Bjrnson leads the evaluation session.

Chapter 39

Cause analysis

This section gives a cause analysis of the groups listed in section 38. It starts with the negative sides and proceeds with the positive.

39.1 Time

In the first phase several comments stated that time had been a problem throughout the project. These were statements such as:

- *"The project group could have worked harder to meet deadlines."*
- *"The group should have been more aware of the project plan, by making the it more visible throughout the project."*
- *"A week-to-week schedule should have been made to better understand the workload."*
- *"Tasks and internal deadlines should have been made more explicit."*

When discussing causes for this, we came up with several reasons to why time had been a problem throughout the project. One of them was that time was in the beginning of the project not considered to be of importance since the deadline was so far ahead. It was also difficult to get started and group members were used to postponing work.

Another reason we discussed was that the first phases of the project seemed uninteresting. As we were not capable of seeing the project as a whole, the use of these phases were not clear to us at that stage. We were not used to spend so much time documenting instead of implementing and progression halted for some time. The meaning of the first phases did though become very clear to us later in the project.

Poor awareness of the project plan was also considered to play a major part. Status was considered on week-to-week basis instead of checking against the plan.

39.2 Design

Design was also considered to be a problem, and several comments stated this:

- *"The design should have been used more thoroughly, and updated more frequently."*
- *"There should have been a greater awareness of the choices of the implementation."*
- *"More members of the group should have been involved in the creation of the design or at least get together and gather a common understanding of the construction."*

When discussing causes to the design problems, we came up with several possible reasons. There was not arranged any internal meeting for discussing the final design, and therefore no mutual understanding. Part of the design was made implicit resulting in confusion regarding interface methods and attributes. There was a low degree of commitment to the design, and we were all looking forward to start coding.

39.3 Requirements

Another prominent problem was the requirements, and the first phase of the evaluation resulted in several comments regarding this:

- *"The group should have done better to prioritise requirements, and skip certain requirements when it turned out to be limited time."*
- *"The group should have required clearer guidelines from the customer regarding the customers intentions with the project."*
- *"The group should have had a more formal interaction with the the customer regarding the requirements."*

When discussing the requirements problems, we realized that a too informal interaction with the customer was the main cause. It was hard to define and understand the scope of the project, which resulted in vague requirements and confusion at first and a week with minimal project progression. The customer was enthusiastic and often thought of new features. We also realised that we did not make as much use as possible of available resources, such as the customer's development team.

39.4 Documentation

During the second phase we agreed upon documentation being a positive part of the project. Two comments regarding this were:

- *"Positive to see the use of the documentation. Inspiring to use results from documentation done earlier in the project."*
- *"Pleased with the pre-study, found it very useful."*

We agreed upon that the pre-study was very useful due to the amount of unknown technology. This was very useful in later phases of the project and clarified the meaning of the early documentation.

39.5 Cooperation

The cooperation within the group was a part of the project which all group members found positive:

- *"No major conflicts."*
- *"No quarreling about the distribution of tasks and workload."*
- *"The cooperation has been very good"*
- *"There has been a good mood and high spirit amongst all group members throughout the project."*

We agreed upon several reason to why the cooperation was a positive side of the project. All group members have approximately the same humor, and everyone is socially intelligent and easy to talk to. We cared about each other, making sure that nobody felt left out. Measurements taken to ensure good cooperation was also decided to play an important role. These measurements was eating pizza together, having regular meeting several times a week, drinking coffee, and participating in courses about teambulding.

39.6 Retrieved knowledge

Retrieved knowledge was a major positive side of the project. Many comments during the second phase were in the course of:

- *"We have learned a lot."*
- *"I have learned C++."*
- *"The tutors have done a good job guiding as."*

Due to the scope of the project, we had to learn a lot of new things. This included new programming languages such as C++ and Python, software development libraries such as VTK, Qt etc. We also had to learn visualisation theory, gesture theory, Linux, LaTeX, communication with hardware devices, relating to a customer and, last but not least, the process of project management.

Chapter 40

Time usage

This section describes the estimated time vs. the actual time used. Time usage for the different project tasks are stated in table 40.1.

	Estimated	Used
Project management	138	325
Lectures and studying	101	244
Planning	201	113
Pre-study	348	291
Requirements specification	218	126
Construction	220	101
Implementation	366	610
Testing	146	277
Evaluation	37	31
Presentation	55	60
Total	1830	2180

Table 40.1: Estimated and used time in the project

As can be seen in the table, estimated time and used time differs. The greatest differences are for the tasks lectures and studying, construction, implementation and testing. There are two main reasons for this: We had no experience with projects of this size and the scope of the project was not known at the time of planning. As a result of this, we have gained experience in estimating time usage and the complexity of such. We have also learned to adjust plans continuously throughout a project.

Chapter 41

Resource evaluation

During this project, we have found help in many sources of assistance. The tutors have been very helpful in their thorough reviews of the documents and proved flexible when we have had a need for extraordinary reviews or late deliveries. They even gave a four-hour evaluation session at the end of the project, giving us a running start on the evaluation part of the report.

We have also had great benefit from the lectures and other courses arranged by the course administration, such as the team-building day. Especially the team-building was beneficial to the general mood in the group, as we were encouraged to talk about issues that we would hesitate to discuss spontaneously.

Regrettably, we have made too little use of the technical competence offered us by the customer, through his developer team and consultant. At the occasions these resources were consulted, an answer was produced quickly and was to great help for the project.

Chapter 42

Fulfillment of success criteria

As stated in section 3.1, the success criteria of the project are:

- The low-level communication library is implemented, tested and found functionally complete with respect to the features of the hardware.
- The middleware providing higher-level functions responds to simple hand gestures and reports picking and movement events.
- The demo application clearly presents the system functionality.

In our project all of these criteria are met. The only comment regarding this is that the low-level communication library could be improved to make use of fully use of the possibilities of the *flock of birds.* This could be done by streaming data instead of the current method which explicitly asks for data every time it is required by a higher layer.

Chapter 43

Remaining work

In order for our product to fully meet the requirements in the requirements specification there are some updates needed to be done by the customer. These updates were discovered through the results of the system test and are also listed in section 30.1.

- Move the *flock of birds* sensor to one of the fingertips in order to track the position at the fingertips. An other possibility would be to set an offset. To compensate for the distance to the fingertips.
- Improve the system for gesture recognition to obtain a higher recognition rate.
- Replace the partly defect right hand glove.

Chapter 44

Future possibilities

The system can be expanded to make use of it's possibilities. Some of these possibilities are:

- Improving gesture recognition.
- Integrate the system with voice recognition.
- Integrate the system with *Blender*, a 3D modeling tool.

Appendix A

Project activities

ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	**Glisa**	**62 days**	**Tue 24.08.04**	**Thu 18.11.04**		
2	Initialization phase	4 days	Tue 24.08.04	Fri 27.08.04		
3	**Planning**	**5 days**	**Mon 30.08.04**	**Fri 03.09.04**	**2**	
13	**Pre Study**	**20 days**	**Mon 06.09.04**	**Fri 01.10.04**	**12**	
33	**Requirement specification**	**15 days**	**Mon 27.09.04**	**Fri 15.10.04**	**31**	
40	**Construction**	**17 days**	**Mon 11.10.04**	**Tue 02.11.04**	**38**	
57	**Implementation**	**18 days**	**Mon 18.10.04**	**Wed 10.11.04**	**45**	
78	**Testing**	**22 days**	**Mon 18.10.04**	**Tue 16.11.04**	**45**	
87	**Evaluation**	**1 day**	**Mon 15.11.04**	**Mon 15.11.04**		
90	**Presentation**	**2 days**	**Tue 16.11.04**	**Thu 18.11.04**	**89**	

Figure A.1: Overall project activities

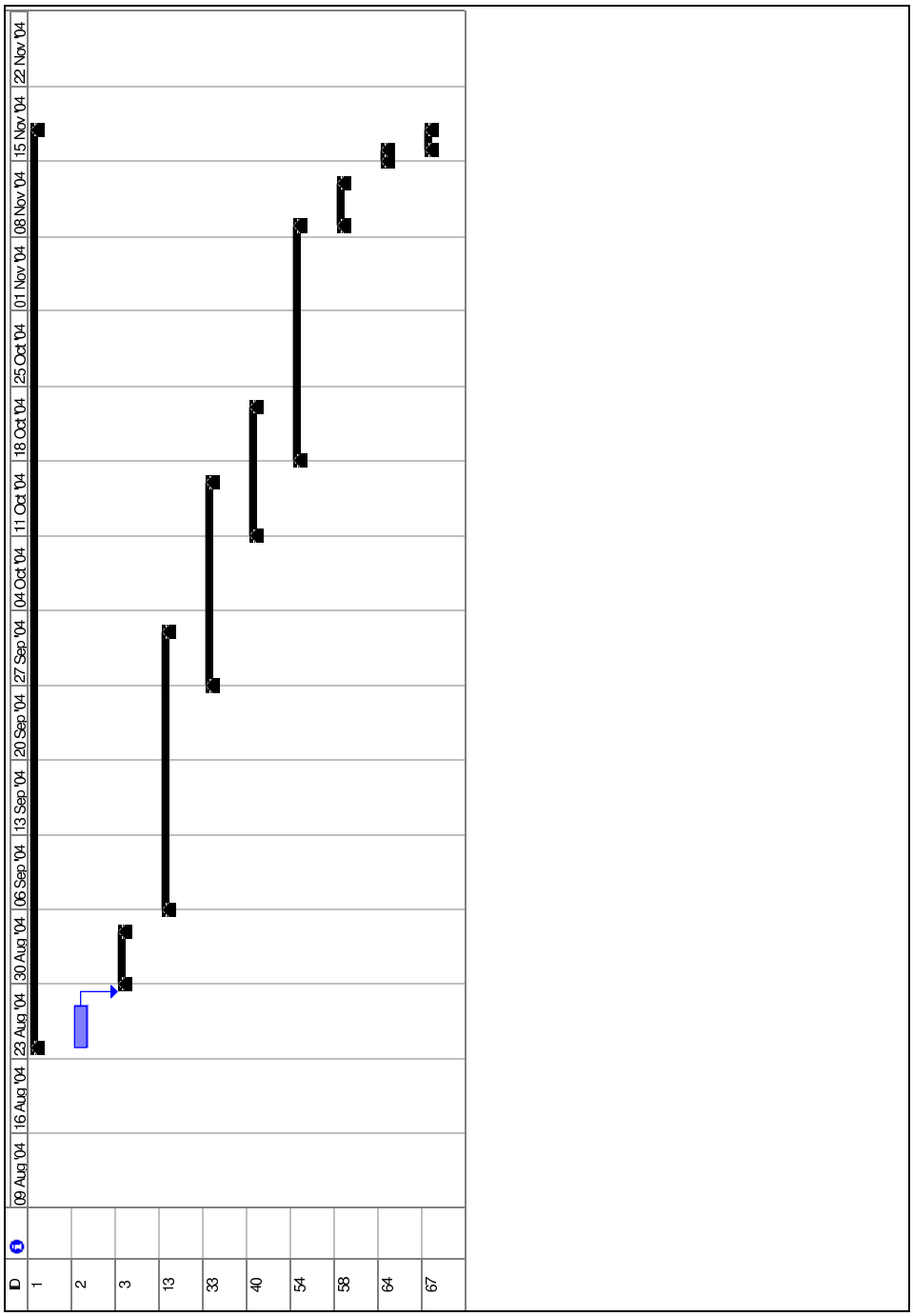


Figure A.2: Gantt diagram showing the overall phases

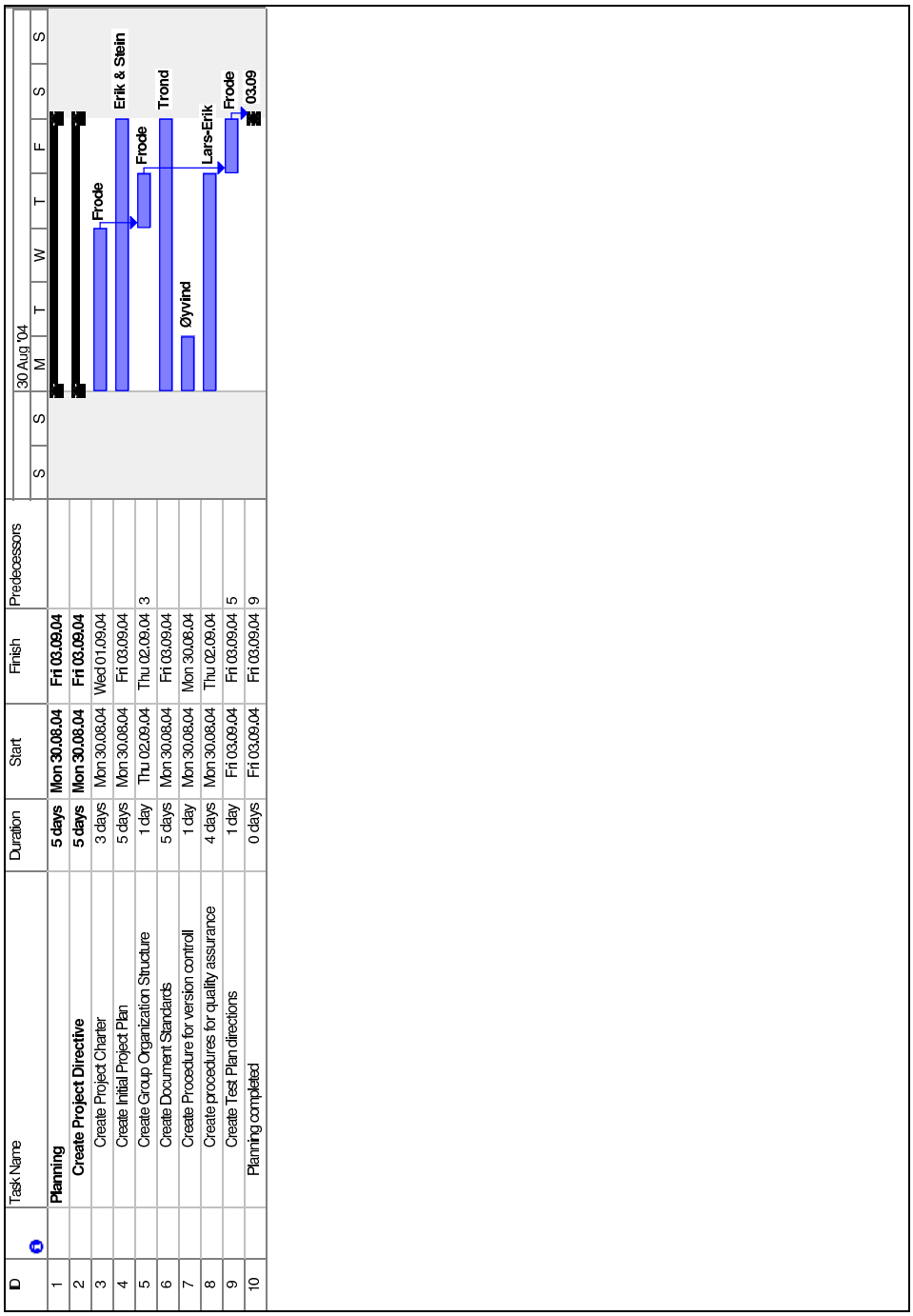

ID
Task Name
Duration
Start
Finish
Predecessors
30 Aug '04
M
T
W
T
F
S
S
1 Planning 5 days Mon 30.08.04 Fri 03.09.04
2 Create Project Directive 5 days Mon 30.08.04 Fri 03.09.04
3 Create Project Charter 3 days Mon 30.08.04 Wed 01.09.04
4 Create Initial Project Plan 5 days Mon 30.08.04 Fri 03.09.04
5 Create Group Organization Structure 1 day Thu 02.09.04 Thu 02.09.04 3
6 Create Document Standards 5 days Mon 30.08.04 Fri 03.09.04
7 Create Procedure for version controll 1 day Mon 30.08.04 Mon 30.08.04
8 Create procedures for quality assurance 4 days Mon 30.08.04 Thu 02.09.04
9 Create Test Plan directions 1 day Fri 03.09.04 Fri 03.09.04 5
10 Planning completed 0 days Fri 03.09.04 Fri 03.09.04 9
Frode
Erik & Stein
Frode
Trond
Øyvind
Lars-Erik
Frode
03.09

Figure A.3: The planning phase

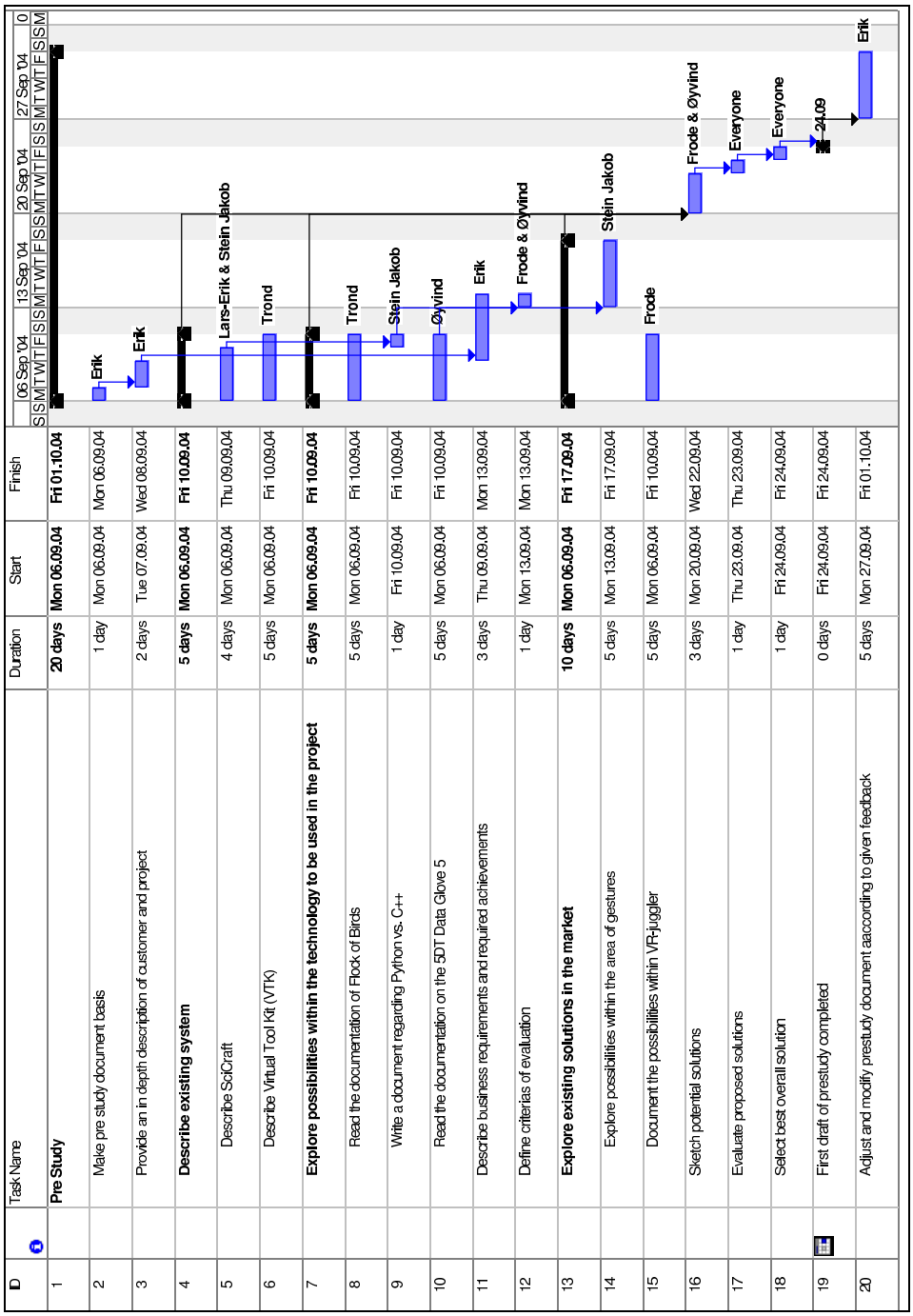

ID
Task Name
Duration
Start
Finish
06 Sep '04
13 Sep '04
20 Sep '04
27 Sep '04
S S M T W T F S S M T W T F S S M T W T F S S M T W T F S S M
1 Pre Study 20 days Mon 06.09.04 Fri 01.10.04
2 Make pre study document basis 1 day Mon 06.09.04 Mon 06.09.04
3 Provide an in depth description of customer and project 2 days Tue 07.09.04 Wed 08.09.04
4 Describe existing system 5 days Mon 06.09.04 Fri 10.09.04
5 Describe SciCraft 4 days Mon 06.09.04 Thu 09.09.04
6 Describe Virtual Tool Kit (VTK) 5 days Mon 06.09.04 Fri 10.09.04
7 Explore possibilities within the technology to be used in the project 5 days Mon 06.09.04 Fri 10.09.04
8 Read the documentation of Flock of Birds 5 days Mon 06.09.04 Fri 10.09.04
9 Write a document regarding Python vs. C++ 1 day Fri 10.09.04 Fri 10.09.04
10 Read the documentation on the 5DT Data Glove 5 5 days Mon 06.09.04 Fri 10.09.04
11 Describe business requirements and required achievements 3 days Thu 09.09.04 Mon 13.09.04
12 Define criterias of evaluation 1 day Mon 13.09.04 Mon 13.09.04
13 Explore existing solutions in the market 10 days Mon 06.09.04 Fri 17.09.04
14 Explore possibilities within the area of gestures 5 days Mon 13.09.04 Fri 17.09.04
15 Document the possibilities within VR-Juggler 5 days Mon 06.09.04 Fri 10.09.04
16 Sketch potential solutions 3 days Mon 20.09.04 Wed 22.09.04
17 Evaluate proposed solutions 1 day Thu 23.09.04 Thu 23.09.04
18 Select best overall solution 1 day Fri 24.09.04 Fri 24.09.04
19 First draft of prestudy completed 0 days Fri 24.09.04 Fri 24.09.04
20 Adjust and modify prestudy document aaccording to given feedback 5 days Mon 27.09.04 Fri 01.10.04
Erik
Erik
Lars-Erik & Stein Jakob
Trond
Trond
Stein Jakob
Øyvind
Erik
Frode & Øyvind
Stein Jakob
Frode
Frode & Øyvind
Everyone
Everyone
24.09
Erik

Figure A.4: The Pre study phase

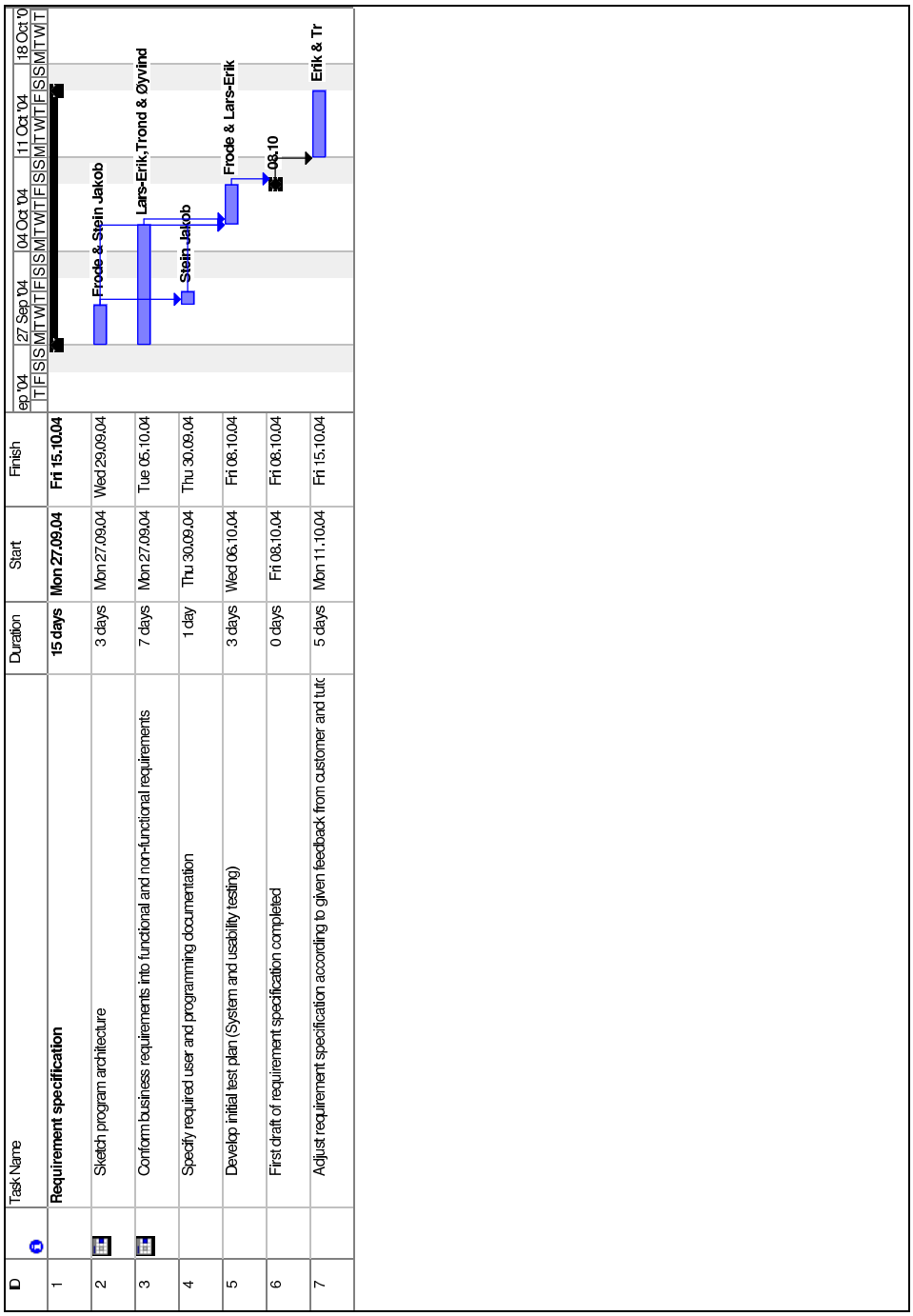

ID
Task Name
Duration
Start
Finish
ep '04
27 Sep '04
04 Oct '04
11 Oct '04
18 Oct '0
T F S S M T W T F S S M T W T F S S M T W T F S S M T W T
1 Requirement specification 15 days Mon 27.09.04 Fri 15.10.04
2 Sketch program architecture 3 days Mon 27.09.04 Wed 29.09.04
3 Conform business requirements into functional and non-functional requirements 7 days Mon 27.09.04 Tue 05.10.04
4 Specify required user and programming documentation 1 day Thu 30.09.04 Thu 30.09.04
5 Develop initial test plan (System and usability testing) 3 days Wed 06.10.04 Fri 08.10.04
6 First draft of requirement specification completed 0 days Fri 08.10.04 Fri 08.10.04
7 Adjust requirement specification according to given feedback from customer and tutc 5 days Mon 11.10.04 Fri 15.10.04
Frode & Stein Jakob
Lars-Erik,Trond & Øyvind
Stein Jakob
Frode & Lars-Erik
08.10
Erik & Tr

Figure A.5: The requirement specification phase

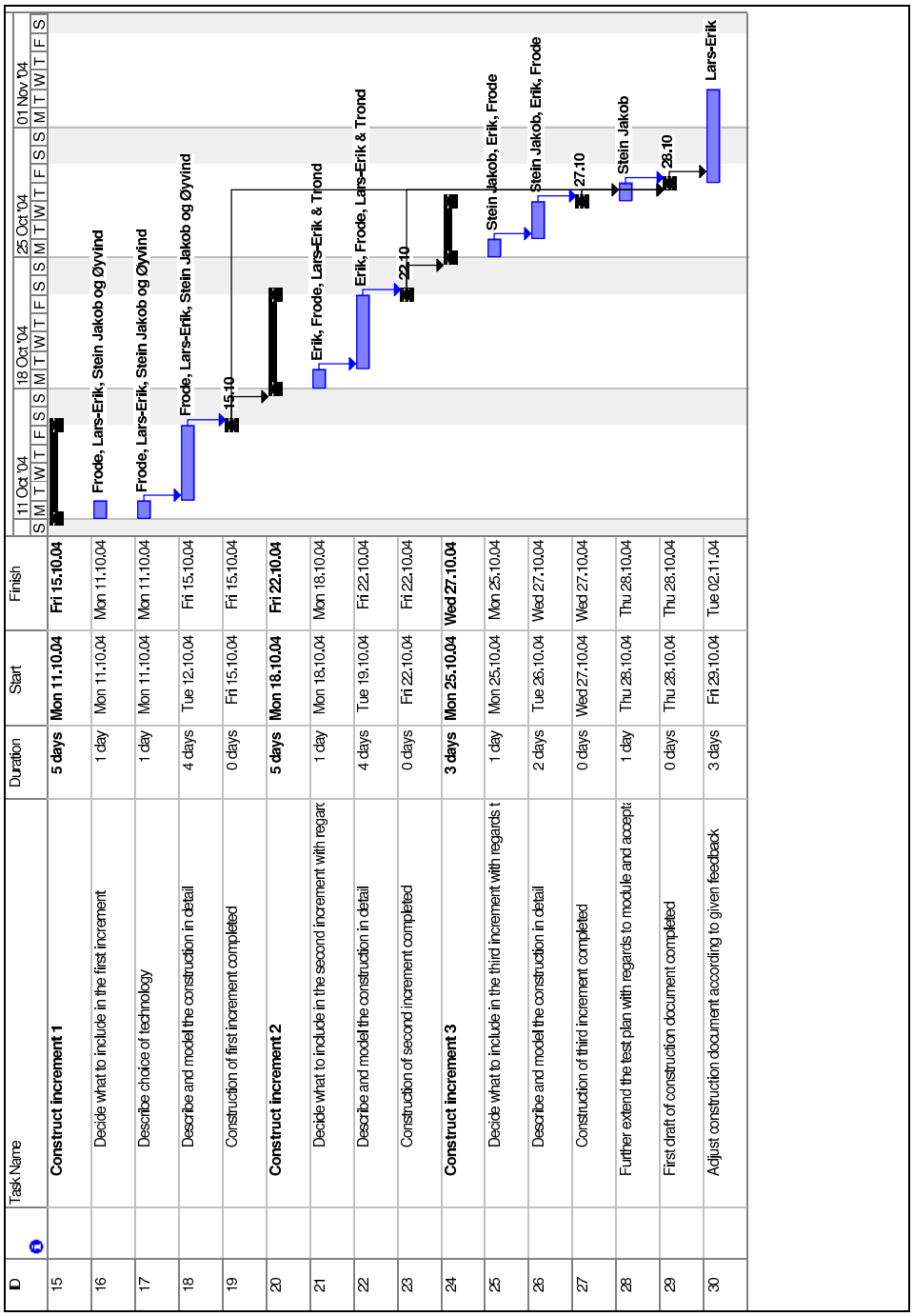

ID
Task Name
Duration
Start
Finish
11 Oct '04
18 Oct '04
25 Oct '04
01 Nov '04
S M T W T F S S M T W T F S S M T W T F S S M T W T F S
15 Construct increment 1 5 days Mon 11.10.04 Fri 15.10.04
16 Decide what to include in the first increment 1 day Mon 11.10.04 Mon 11.10.04
17 Describe choice of technology 1 day Mon 11.10.04 Mon 11.10.04
18 Describe and model the construction in detail 4 days Tue 12.10.04 Fri 15.10.04
19 Construction of first increment completed 0 days Fri 15.10.04 Fri 15.10.04
20 Construct increment 2 5 days Mon 18.10.04 Fri 22.10.04
21 Decide what to include in the second increment with regar 1 day Mon 18.10.04 Mon 18.10.04
22 Describe and model the construction in detail 4 days Tue 19.10.04 Fri 22.10.04
23 Construction of second increment completed 0 days Fri 22.10.04 Fri 22.10.04
24 Construct increment 3 3 days Mon 25.10.04 Wed 27.10.04
25 Decide what to include in the third increment with regards t 1 day Mon 25.10.04 Mon 25.10.04
26 Describe and model the construction in detail 2 days Tue 26.10.04 Wed 27.10.04
27 Construction of third increment completed 0 days Wed 27.10.04 Wed 27.10.04
28 Further extend the test plan with regards to module and accepta 1 day Thu 28.10.04 Thu 28.10.04
29 First draft of construction document completed 0 days Thu 28.10.04 Thu 28.10.04
30 Adjust construction document according to given feedback 3 days Fri 29.10.04 Tue 02.11.04
Frode, Lars-Erik, Stein Jakob og Øyvind
Frode, Lars-Erik, Stein Jakob og Øyvind
Frode, Lars-Erik, Stein Jakob og Øyvind
15.10
Erik, Frode, Lars-Erik & Trond
Erik, Frode, Lars-Erik & Trond
22.10
Stein Jakob, Erik, Frode
Stein Jakob, Erik, Frode
27.10
Stein Jakob
28.10
Lars-Erik

Figure A.6: The construction phase

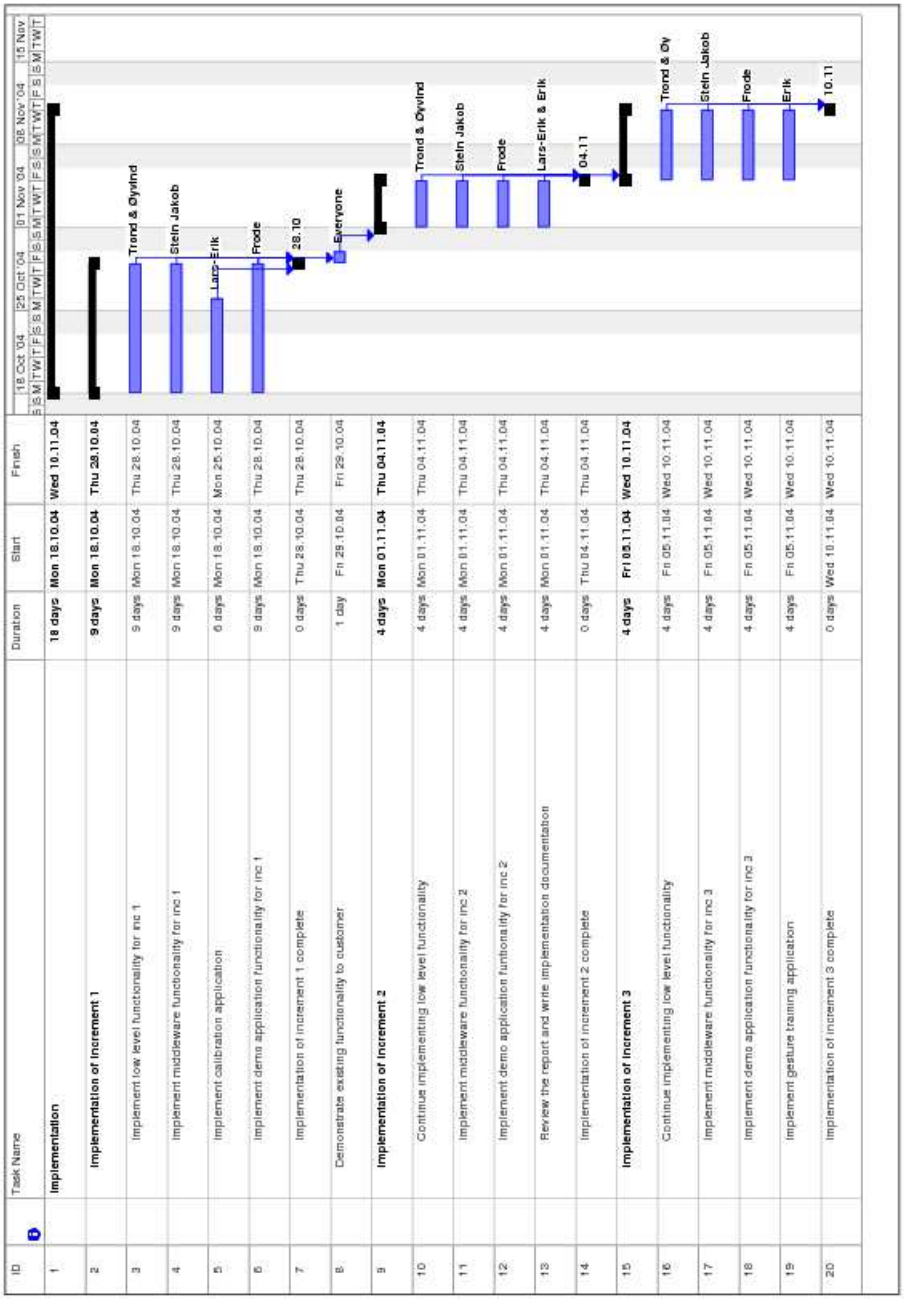
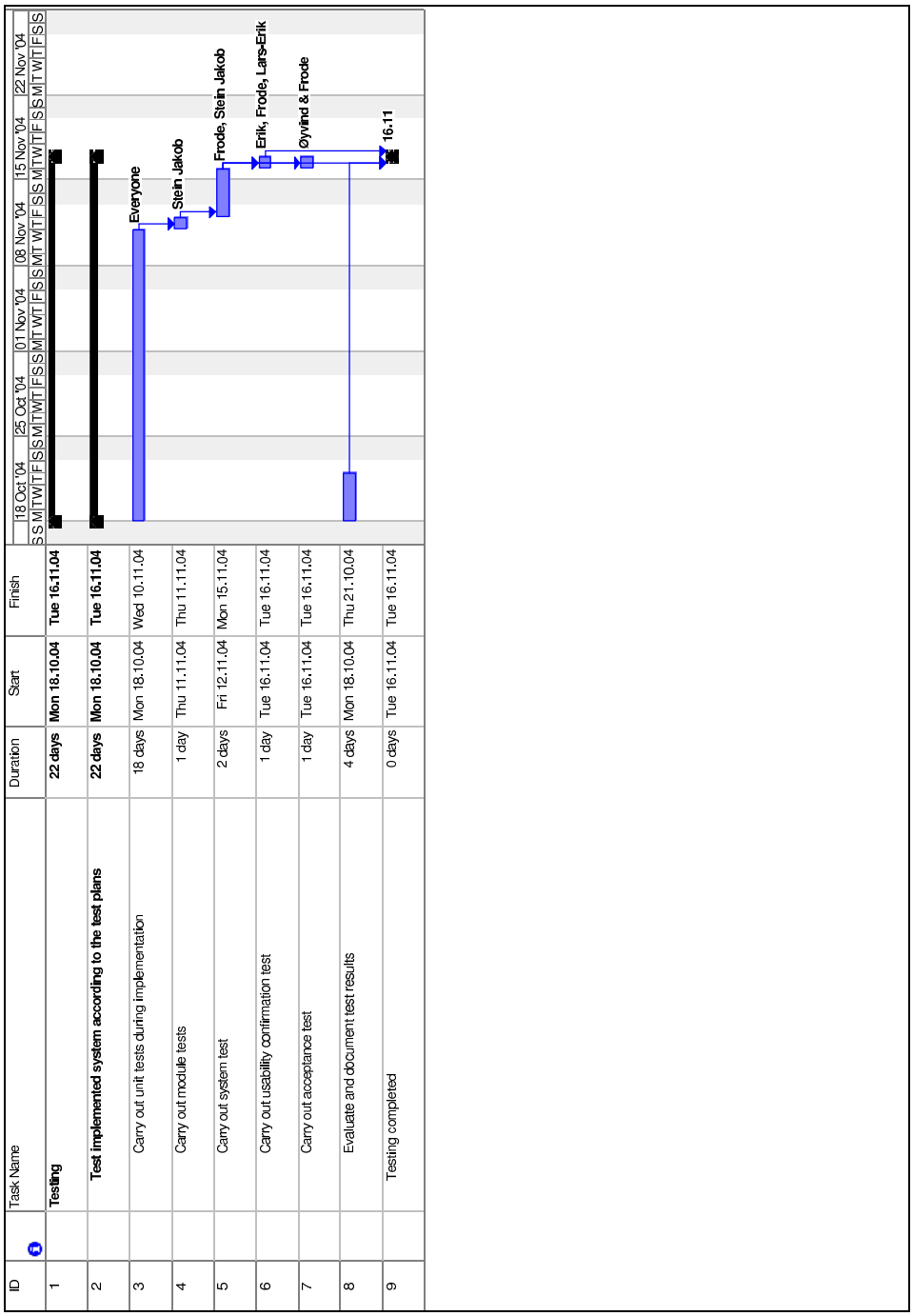


Figure A.7: The implementation phase



ID	Task Name	Duration	Start	Finish
1	**Testing**	**22 days**	**Mon 18.10.04**	**Tue 16.11.04**
2	**Test implemented system according to the test plans**	**22 days**	**Mon 18.10.04**	**Tue 16.11.04**
3	Carry out unit tests during implementation	18 days	Mon 18.10.04	Wed 10.11.04
4	Carry out module tests	1 day	Thu 11.11.04	Thu 11.11.04
5	Carry out system test	2 days	Fri 12.11.04	Mon 15.11.04
6	Carry out usability confirmation test	1 day	Tue 16.11.04	Tue 16.11.04
7	Carry out acceptance test	1 day	Tue 16.11.04	Tue 16.11.04
8	Evaluate and document test results	4 days	Mon 18.10.04	Thu 21.10.04
9	Testing completed	0 days	Tue 16.11.04	Tue 16.11.04

Figure A.8: The testing phase

Figure A.9: The evaluation phase

Figure A.10: The presentation phase

Appendix B

Templates

B.1 Summons

Møteinnkalling

<møtets tittel>

Dato:	dd.mm 2004
Tid:	tt.mm-tt.mm
Sted:	<møtested>
Møteleder:	<navn>
Referent:	<navn>
Til:	Øyvind Bø Syrstad, Erik Rogstad, Trond Valen, Frode Ingebrigtsen, Lars-Erik Bjørk, Stein Jakob Nordbø, Jahn Otto Andersen, Bjørn K. Alsberg, Finn Olav Bjørnson, Anne Kristine Reknes.

Agenda

1. Sak 1
2. Sak 2
3. ...
4. Eventuelt

B.2 Status report

Statusrapport

Uke <ukenummer>

Generelt

Utført arbeid i perioden

- Arbeidsoppgave 1
- Arbeidsoppgave 2 ...
- Status for dokumenter som skal utarbeides.

Møter

- Møter foregående uke.

Aktiviteter

- Aktiviteter foregående uke.

Annet

- Annet.

TROKK

Tid	<hvordan ligger vi an tidsmessig?>
Risiko	Se vedlagt risikoplan.
Omfang	<utdype evt. endringer i oppgavens omfang>
Kostnad	Se vedlagte timelister.
Kvalitet	<er det noe som tilsier at kvaliteten må reduseres?>

Problemer

- Problemer vi har møtt forrige uke.

Planlagt arbeid neste periode

- Møter
- Aktiviteter
- Annet

B.3 Minutes

Møtereferat

<møtets tittel>

Dato:	dd.mm 2004
Tid:	tt.mm-tt.mm
Sted:	<møtested>
Møteleder:	<navn>
Referent:	<navn>
Tilstede:	Øyvind Bø Syrstad, Erik Rogstad, Trond Valen, Frode Ingebrigtsen, Lars-Erik Bjørk, Stein Jakob Nordbø, Jahn Otto Andersen, Bjørn K. Alsberg, Finn Olav Bjørnson, Anne Kristine Reknes.
Ikke tilstede:	Ingen.

Agenda

1. Sak 1
2. Sak 2
3. ...
4. Eventuelt

Resultater

1. Resultat 1
2. Resultat 2
3. ...

Plan for neste uke

Hvem	Oppgave
du	gjør alt

B.4 Phase documents

Use the project directive as a template

Appendix C

Stakeholders

Customer

Bjørn K. Alsberg	bka@phys.chem.ntnu.no	73 59 41 84/924 66 021
Jahn Otto Andersen	jotto@jotto.no	

Project group

Øyvind Bø Syrstad	oyvindsy@stud.ntnu.no	984 78 304
Erik Rogstad	erikrog@stud.ntnu.no	456 00 663
Trond Valen	valen@stud.ntnu.no	913 36 275
Frode Ingebrigtsen	frodein@stud.ntnu.no	971 51 440
Lars-Erik Bjørk	larserb@stud.ntnu.no	926 17 428
Stein Jakob Nordbø	steinjak@stud.ntnu.no	918 36 164

Tutors

Finn Olav Bjørnson	bjornson@idi.ntnu.no	73 59 87 16
Anne Kristine Reknes	annekr@stud.ntnu.no	

Appendix D

Risk table

In the following tables, the risks are listed with the following fields:

Risk-ID Number uniquely identifying the risk.

A descriptive name of the risk

Textual representation of the consequence

C Consequence, rated as high (10), medium (3) or low (1).

P Probability, rated as high (10), medium (3) or low (1).

R Risk, $R = C \cdot P$.

Preactive Measure to prevent the risk from occurring.

Reactive Measure to minimise the damage of occurring risks.

Res Person responsible for carrying through the measure.

Risk-ID	A descriptive name of the risk	Textual representation of the consequence	C	P	R	Preactive	Res	Reactive	Res
1	Drivers don't work properly	Additional work which may result in deadlines not being met, and in frustration	10	1	10	Test drivers thoroughly	Øyvind	Search for new drivers, consider writing drivers ourselves	Frode
2	Hard to get hold of the customer	Progression may halt as vital information may not be available, there may be misunderstandings and wrong functionality may be implemented	10	10	100	Close cooperation with the customer, according to the quality assurance plan. Make sure the customer is aware of the agreed response times. Be sure the customer frequently checks is e-mail account. Make sure customer is reachable through more than one medium.	Frode	Report the situation to the tutors. If the progression halts completely, use the time for quality-assurance of results achieved so far.	Lars-Erik
3	Customer adds requirements during the development	Additional work which may result in deadlines not being met, and in frustration	3	3	9	Review the system requirements plan thoroughly with the customer. Make sure the plan is approved by the customer before moving on to the next phase	Frode	Review the schedule and chose between delegating the additional workload or rejecting the added requirements	Trond
4	Disease among the group members	Additional work for remaining group members may result in deadlines not being met, and in frustration	3	3	9	All group members should eat healthy food such as vegetables and fish. All members should also take C-Max or Vitamin C, and make sure to get enough sleep. Enough clothes are also to be used	All members	Delegate the workload and possibly lower the level of quality	Lars-Erik
5	Poor cooperation with the customer	There may be misunderstandings in the work to be done, requirements etc. This may lead to frustration for both the group and the customer and may decrease the customer's feeling of the product quality	10	3	30	Agree with the customer how close the cooperation is supposed to be. Have regular meetings and give continuous feedback to the customer showing current project status	Erik	Arrange meetings with the customer to discuss what can be done to improve the cooperation	Frode

Risk-ID	A descriptive name of the risk	Textual representation of the consequence	C	P	R	Preactive	Res	Reactive	Res
6	Poor cooperation within the group	Several group members may be working on the same, resulting in additional cost. The progression may halt as it is hard to get hold of information potentially vital for the project	10	1	10	Write summons from all meetings according to the project directive, and have regular internal meetings. Five minutes at the end of all weekly internal meetings should be used to discuss everybody's opinion of the group cooperation. All group members should report the status of their work regularly	Lars-Erik	Arrange internal meetings to discuss the current situation and the possible solutions for improving the cooperation	Erik
7	Individual group members don't carry their own weight	Additional work on remaining group members may result in deadlines not met, and in frustration. It may result in conflicts between group members	10	1	10	All group members should come forward with their goals for the project. If any of the members knows any reason to why they may not be able to give 100 percent, they should state this as early in the process as possible so this may be taken into consideration when planning the project costs	Stein Jakob	Arrange internal group meetings to discuss the situation with the respective group members. If the situation does not seem to improve, reporting the respective student to the tutors should be taken into consideration	Erik
8	Group members are traveling	Additional work on remaining group members may result in deadlines not met, and in frustration	3	3	9	Group members should notify the rest of the group as early as possible about traveling plans	All members	Review the schedule and chose between delegating the additional workload or lowering the level of quality	Stein Jakob
9	Group members may for shorter periods of time have to give other courses higher priority	This may lead to frustration and conflict within the group, as different group members may have different opinions on the importance of the project vs other courses. It may also lead to additional work for the remaining group members. This may lead to deadlines not being met	3	10	30	All group members should make a schedule for all hand-ins in other courses. A plan should be made so that the project workload is evened out between the group members. The workload may have to be a little heavier the week(s) before the hand-ins	Trond	Review the schedule and chose between delegating the additional workload or lowering the level of quality	Trond

Risk-ID	A descriptive name of the risk	Textual representation of the consequence	C	P	R	Preactive	Res	Reactive	Res
10	Group members may experience personal crisis	The person experiencing the crisis may not be able to carry out his part of the job. It may lead to increased workload on the remaining group members, and in deadlines not being met. It may result in poor project participation, and ruin the otherwise cheerful mood	10	1	10	Take time to see the signs of burned out group members.	Erik	Delegate assignments to other members and help the member get out of the crisis	Øyvind
11	Development software may not function as expected	This may lead to great frustration for the developers. It may be costly to switch development software during development, it may result in an increased workload in training etc	3	3	9	Ensure that all members know how to use the development software, as this may be a reason for the malfunction.	Frode	Consider either development software, contact the ones in charge of maintaining the software or experts within the software.	Trond
12	Integrated open-source-code doesn't function as expected	This may lead to additional costs when the group may have to search for alternative open-source-code or write their own. This may lead to deadlines not being met	3	3	9	There should in the quality assurance plan be a procedure for assuring the quality of open-source-code. This procedure should be followed strictly	Lars-Erik	Consider to either correcting the faults ourselves or finding better solutions, and review the schedule	Øyvind
13	Parts of the project may be more costly than planned	Additional work which may result in deadlines not met, and in frustration for the group members	3	3	9	Take care of planning properly before commencing work on a new phase.	Erik	Remove some of the less important requirements.	Stein Jakob

Risk-ID	A descriptive name of the risk	Textual representation of the consequence	C	P	R	Preactive	Res	Reactive	Res
14	Conflicts amongst the group members	If not solved ,this may lead to poor communication and cooperation within the group. The level of motivation may drop	1	10	10	The preactive measure is in part covered by pt.6. For avoiding the non work-task-related part of the possible internal conflict, the group should meet for social activities. Doing this regularly would probably destroy the intention, therefore such activities should be arranged when all the group members feel for it.	Erik	Conflict resolution; first between the persons in question, and eventually in the full group. As a last resort, the tutors will be made aware of the problem.	Erik
15	Unsatisfactory distribution of information/documentation	Progress may halt for a period of time if crucial information is unreachable. This may result in an increased workload for a period if time	1	3	3	There should in the quality assurance plan be a procedure for assuring the distribution of information and documentation. This procedure should be followed strictly.	Trond	The person(s) responsible for the document(s) will be alerted and asked to get the documents as quickly as possible. If this doesn't help, responsibility is delegated to somebody else.	Frode

Appendix E

Abbreviations and terms

This is a list of the abbreviations and terms used in this prestudy document. The list contains both abbreviations and terms interleaved in alphabetical order. Both terms and abbreviations are in bold types. After abbreviations, the long version is listed, followed by a period and an explanation. Terms are followed simply by the explanation or definition.

5DT Fifth Dimension Technologies. A high-technology company spesializing in virtual reality.

5DT Data Glove 5 . Gloves for virtual reality from 5DT.

API Application Programmer's Interface. An external interface of a software package that simplifies its use.

Ascension-Tech Ascension Technology Corporation. A producer of motion tracking devices.

Azimuth Rotation about the Z axis

C++ A programming language.

CBG Chemometrics and Bioinformatics Group. Our customer's group in the Institute of Chemistry at NTNU.

Elevation Rotation about the Y axis

FBB Fast Bird Bus A signaling interface for interconnecting multiple sensors in *Flock of Birds*.

Flock of Birds A hardware device for motion tracking with multiple actors.

FSM Finite state machine A conceptual device that stores the status of variables and changes the status on the basis of input signals. Often used in artifical intelligence applications.

Gadgeteer A part of VR Juggler that provides drivers for input devices and abstractions of input data.

Glisa Glove is in the Air. The name of the project.

GPL GNU General Public License. A license for open source project.

GUI Graphical User Interface. The part of a program that is displayed to the user.

HCI Human Computer Interaction. The science of facilitating human interaction with computers.

Hololib A library for communication with *Flock of Birds* and a home-made VR glove.

Holomol A demo application that shows the features of Hololib.

HMM Hidden Markov Models. A doubly stochastic state machine operating on sequential strings of symbols in a finite alphabet.

IDIAP Dalle Molle Institute for Perceptual Artificial Intelligence. A semi-private research institution in Switzerland.

Java A programming language.

Neural network A conceptual device that classifies combinations of multiple input signals. It consists of interconnected Threshold Logic Units.

NTNU Norwegian University of Technology and Science.

OpenGL A graphics package.

Open Inventor A graphics package.

Pitch Bending and flexing the wrist as when revving a motorcycle.

PyMol An application for creating and manipulating molecules in 3D.

Python A programming language.

Roll Flock of Birds context: Rotation about the X axis.
5DT Data Glove 5 context: Rotation of the hand about the axis of the arm.

RS-232 A serial signaling interface, used in *Flock of Birds*.

RS-485 A serial signaling interface, used in *Flock of Birds*.

SciCraft A tool for computer data analysis developed at the Chemometrics and Bioinformatics Group.

ST-FFT Short-Time Fast Fourier Transform A Fast Fourier Transform performed on a small window of input data.

ST-FT Short-Time Fourier Transform A Fourier Transform performed on a small window of input data.

STL standard library. The basic features of a programming language.

Tcl/Tk A programming language.

TDT4290 Customer Driven Project The course at NTNU that assigned us this project.

TLU Threshold Logic Unit The components of a neural network.

Torch A software library implementing Hidden Markov Models.

Tilt Common term for both roll and pitch.

VQ Vector quantiser A module used for preprocessing the Hidden Markov Models input signals into discrete symbols.

VTK Visualization Toolkit A graphics package from Kitware.

VR Virtual Reality.

VR Juggler A platform for development of virtual reality applications with support for a wide range of input devices.

Appendix F

Gesture recognition details

F.1 Elaboration of Hidden Markov Models

Discrete Hidden Markov Models are to be used for gesture recognition. These must be configured and trained before they can be used for recognition. Also, the input needs preprocessing to reduce the workload and increase the recognition rate.

This section treats each of the above topics separately, but leaves out some detail on certain concepts that are explored in greater depth in the next few sections in this appendix. Training and recognition can be done by an external library. Such a library, *Torch*, was introduced in section 17.2.5 and in this section we will explain how to use that library in our project.

F.1.1 Input preprocessing

Discrete Hidden Markov Models operate on sequences of discrete symbols, so the input from the gloves (possibly 6 degrees of freedom in space plus five fingers for each hand) need preprocessing. Additionally, the data stream will quickly reach a volume that is infeasible for real-time recognition if it is not condensed to a more concise format.

The HMMs may be one- or multidimensional, a n-dimensional HMM accepting input of n dimensions. We will, however, stick to one-dimensional HMMs for simplicity in the spirit of [LX96]. This means that we will need a Vector Quantiser (VQ) to quantise the multidimensional input vectors into discrete symbols. The VQ classifies vectors by calculating the deviation of each vector from a prototype in a *codebook*, a table of classification vectors. The codebook can be generated from a sample set of vectors by the *LBG algorithm* ([JYYX94]). See appendix F.3 for more on Vector Quantisers.

Before the signals are run through the VQ, it is advantageous to do some initial preprocessing on them. One popular preprocessing is the Short-Time Fast Fourier Transform (ST-FFT), which is a Fourier Transform performed on a small window of the input data. This makes the magnitude of the processed data independent of time-shift of the signal within the window, at the same time as preserving all information present in the original signal. Temporal information is preserved because

of the windowing ([JYYX94]). More information on ST-FFT can be found in appendix F.4.

For the data to be used with the ST-FFT algorithm, it needs to be windowed. This is simply done by partitioning the data stream in equally sized fragments, with a certain overlap to prevent loss of information.

When windowing the data and performing the Fourier Transform, artifacts arise because of the sudden cutoff at the edges. This is in particular the effect of the function $\text{sinc}(x) = \frac{\sin(x)}{x}$, which is the Fourier Transform of a rectangle. The solution to this problem is smoothing out the edges with the *Hamming function*,

$$w[n] = 0.54 - 0.46 \cos\left(\frac{2\pi n}{N}\right) \tag{F.1}$$

for each sample in the window w of length N.

Another function that might prove useful is resampling, either it is to undersample data arriving at a very frequent rate (the system used by [LX96] samples at 10 Hz, while the *Flock of Birds* is capable of delivering data up to 100 Hz), or to resample data to achieve regularly spaced sampling intervals. This is typically the first step in a preprocessor.

The preprocessing stage can be summarised by figure F.1 (inspired by the preprocessor used by [LX96]).

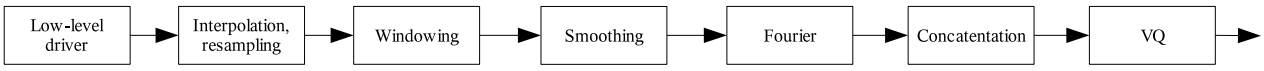


Figure F.1: The preprocessor stage in the gesture recogniser

In this diagram, several inputs flow into the preprocessor from the low-level drivers. All units operate on each data flow separately (from the assumption that the inputs are mutually stochastic independent), until the Concatenation stage builds a large vector with one element per stream that is given as input to the VQ, which outputs a single discrete observation symbol to be used with the HMM. In the final implementation, there may not be a need for all stages of preprocessing. We delay that decision until a later stage, when we have the opportunity to experiment. One moment to consider, is to remove the ST-FFT if we use positional data only, as that greatly simplifies VQ design (one could simply partition the euclidian space into cells, assigning a unique number to each cell as a codeword).

F.1.2 Configuration considerations

One important aspect of setting up an HMM is *topology*. Topology refers to the possible transitions between states; a transition is possible if and only if the corresponding transition probability is nonzero. There are several types of topology, the most important are listed below:

- Left-to-right topology – Transitions to a previously visited state (back in time) are not allowed.

- Bakis topology – The system is restricted to move to the same state or one of the two next states.
- Ergodic topology – No restrictions on possible state transitions, the system is fully connected.

In problems that relate to recognising time-sequent information, one usually configures the HMMs in a left-to-right fashion (Bakis topology is used by [LX96]). This also reduces the computational load incurred by the training and decoding algorithms (recognising a gesture is done by *decoding* the sequence of observations into the most probable sequence of hidden states).

Figures F.2 and F.3 show HMMs with left-to-right and ergodic topologies, respectively. Transitions are marked with probabilities, where a_{ij} is the probability that a transition from state i to state j will occur. Illegal/impossible transitions (with zero probability) are not shown. See appendix F.2 for more information on transition probabilities.

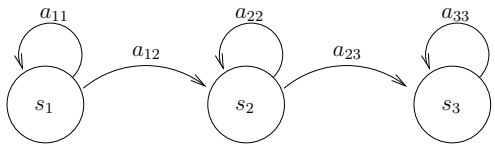


Figure F.2: HMM with left-to-right topology

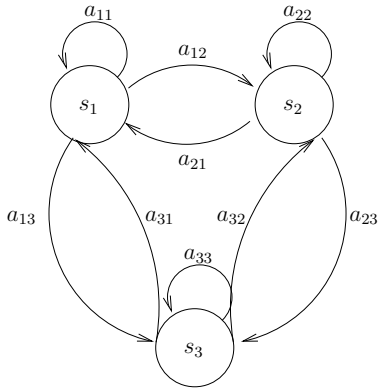


Figure F.3: HMM with ergodic topology

Another aspect of configuration is how to recognise one gesture amongst many different alternatives, each represented by one HMM. One alternative is to run the *evaluation algorithm* (calculating the probability of the most probable sequence of hidden states) on each of the HMMs and then choosing the gesture giving the highest probability. This enables the system to discover situations where two HMMs give nearly equal probabilities (ambiguity) or where the most probable gesture is not sufficiently probable ([LX96]). Another possibility is to create one huge HMM where all the individual gesture HMMs are configured in parallel, with a start and end super-node (see figure F.4). This structure would probably identify gestures more efficiently, and it could be used for continuous recognition by adding a transition from the end super-node to the start super-node ([JYYX94]).

F.1.3 Training strategy

A Hidden Markov Model is usually trained by using a set of examples and running a training algorithm on the entire batch. One such training algorithm is the *Baum-Welch algorithm*. It is an iterative

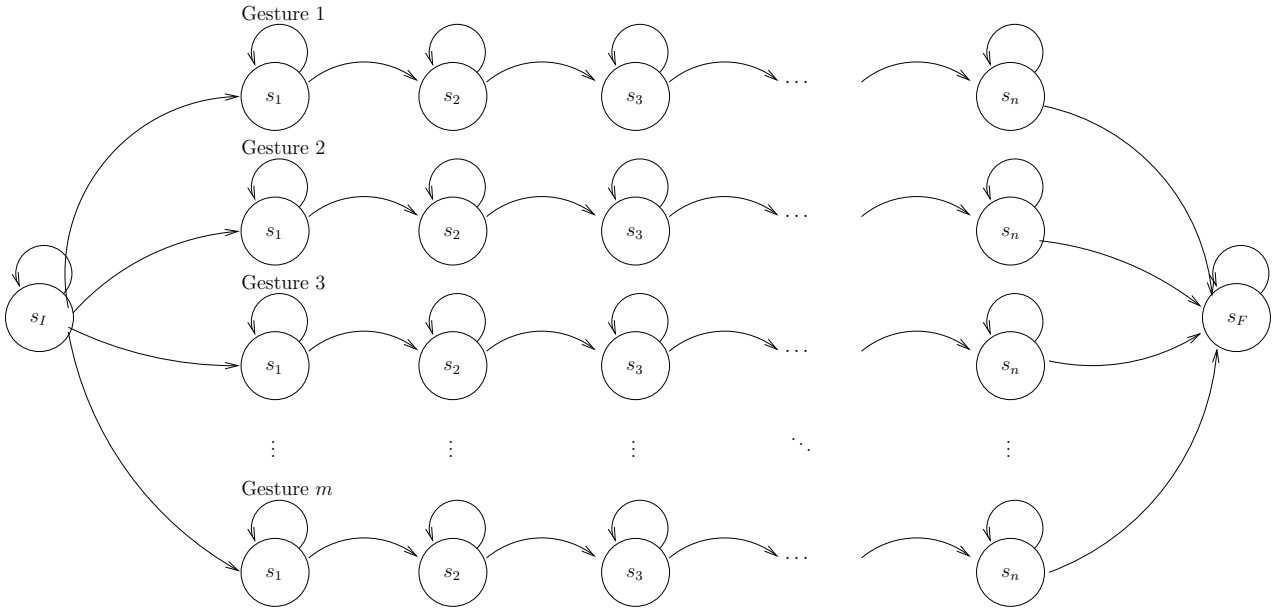


Figure F.4: Parallel organisation of HMMs

algorithm that progressively refines the transition and emission probabilities until some measure of convergence is satisfied ([RODS01]). More information on HMM training can be found in the appendix on mathematical background, appendix F.2.2.3.

[LX96] has shown that good results may also be achieved with online learning of gestures, training the HMM as new examples are added. However, the capabilities of their system is still not quite as good as for an off-line-trained system, and considering that the need for addition of new gestures is relatively rare, we choose not to include this functionality in our product. Nevertheless, it may be an interesting point of extension in a later version of the software.

F.1.4 Using the external library Torch

We have in section 17.2.5 introduced and evaluated an external library, Torch. Now we will explain how to use the library from a programmer's point of view. Adapting Torch to our project will require the following:

- Instantiating the class `Multinomial` for each state and initialising with the size of the codebook from the VQ.
- Instantiating the class `HMM` and initialising with the multinomial distributions for each state, in addition to the topology of the HMM ([JYYX94] has experienced that using uniform distribution of initial transition probabilities gives good results).
- Possibly subclassing `SeqDataSet` if we want to embed HMM configuration/training data in our own file format. Another possibility is to write a class to extract data from the data-structures manually and then use another part of the program to actually write the data.

F.2 Mathematical background for Hidden Markov Models

This chapter is mainly researched from [RODS01] and [Ben97]. The notation for sequences of variables is adapted from [Ben97], $y_{t_1}^{t_2}$ representing the sequence $\{y_{t_1}, y_{t_1+1}, \ldots, y_{t_2}\}$. Uppercase variable names denote stochastic variables, while the corresponding lowercase letters refer to one specific value taken by that variable, i.e. $P(q_1)$ is equivalent to $P(Q_1 = q_1)$.

F.2.1 The mathematical background

When modelling processes that unfold in time, it may be favourable to view these processes as a sequence of states. In such problems, Hidden Markov Models are found appropriate, and these are built on a foundation of Markov models. A discrete Markov model of order k is a probability distribution over the state variables $Q_1^t = \{Q_1, Q_2, \ldots, Q_t\}$ satisfying the conditional independence property

$$P(q_t|q_1^{t-1}) = P(q_t|q_{t-k}^{t-1}) \tag{F.2}$$

This simply means that the state attained at time t, q_t, is only dependent on the last k states (q_{t-k}^{t-1}), not on the entire history of states.

The joint distribution $P(q_1^T)$ may by eq. F.2 be written as (the first transformation is a factorisation theorem for sequences $Q_1^T = \{Q_1, Q_2, \ldots, Q_T\}$):

$$P(q_1^T) = P(q_1)\prod_{t=2}^{T} P(q_t|q_1^{t-1}) = P(q_1^k)\prod_{t=k+1}^{T} P(q_t|q_{t-k}^{t-1}) \tag{F.3}$$

As the number of parameters needed to parameterise the model grows exponentially with k, the problem of operating on a Markov Model of order k quickly becomes intractable for increasing values of k. In our setting, we will therefore only consider models of order one , yielding a simpler expression for the joint distribution:

$$P(q_1^T) = P(q_1)\prod_{t=2}^{T} P(q_t|q_{t-1}) \tag{F.4}$$

Again, the interpretation is quite simple: Given a state sequence, Q_1^T, and a set of time-independent probabilities, $\{P(q_t|q_{t-1})|t = 2..T\}$, just multiply all the probabilities. For example, say that the state sequence is $Q_1^T = \{s_1, s_3, s_1, s_2, s_2\}$ and the transition probabilities are given by a_{ij}, the probability that a transition will occur from state i to state j for $i, j \in \{1, 2, 3\}$ (see figure F.5). Then, the probability that this particular sequence will occur is $a_{13}a_{31}a_{12}a_{22}$ multiplied with the probability that we are in state s_1 initially, $P(s_1)$.

It is not given that the process we are modelling – gestures performed by humans – is Markovian (i.e. equation F.2 holds) for small k, but if we assume that the observation sequence Y_t warrants that the past data at time t may be summarised by a state variable, we can model from it an underlying Markovian process Q_t. This is called a *Hidden Markov Model*, because we cannot observe the assumed Makrovian process Q_t.

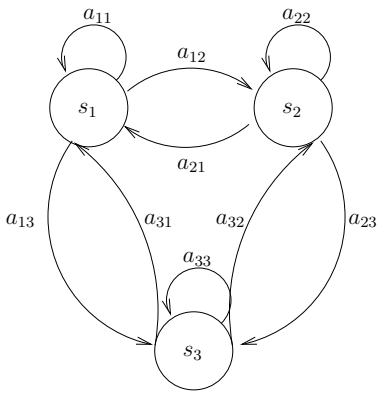


Figure F.5: Markov model with three states

For Hidden Markov Models, $P(y_t|q_1^t, y_1^{t-1}) = P(y_t|q_t)$ and $P(q_{t+1}|q_1^t, y_1^t) = P(q_{t+1}|q_t)$ holds, and the joint distribution is:

$$P(y_1^T, q_1^T) = P(q_1) \prod_{t=1}^{T-1} P(q_{t+1}|q_t) \prod_{t=1}^{T} P(y_t|q_t) \tag{F.5}$$

The interpretations of the independence properties are as follows: $P(y_t|q_1^t, y_1^{t-1}) = P(y_t|q_t)$ means that the output in state q_t is invariant of earlier output and state history, and $P(q_{t+1}|q_1^t, y_1^t) = P(q_{t+1}|q_t)$ means that the state transitions are independent of earlier output.

To parameterise this model, three sets of probabilities are needed, the transition probabilities, $P(q_{t+1}|q_t)$, the emission probabilities, $P(y_t|q_t)$, and the initial distribution, $P(q_1)$. Under these assumptions, in addition to the assumption that output and transitions are time-independent (a homogenous model), both state transition and output probabilities only rely on the current state. Thus, we may represent these using one matrix for the transition probabilities a_{ij} and one matrix for the output probabilities $b_j(O_k)$.

We have now arrived at the definition given by [JYYX94], introducing standard notation for the model $\lambda = (A, B, \pi)$ in computer science usage of HMMs:

1. $\{S\}$, a set of states (including initial state, S_I, and final state, S_F).
2. $A = \{a_{ij}\}$, the transition probability matrix. a_{ij} denotes the probability that a transition will occur from state i to state j.
3. $B = \{b_j(O_k)\}$, the output probability matrix. $b_j(O_k)$ denotes the probability that the discrete observation symbol O_k is observed in state b_j.
4. $\pi = \{\pi_i\}$, the distribution of the initial state.

The following properties hold:

- All probabilities are positive or zero:

$$a_{ij} \geq 0 \, , b_j(O_k) \geq 0 \text{ for } \forall i, j, k \tag{F.6}$$

- For each time step, a transistion is made (possibly from the original state back to itself):

$$\sum_j a_{ij} = 1 \text{ for } \forall i \tag{F.7}$$

- For each time step, the emission of an output symbol is present:

$$\sum_k b_j(O_k) = 1 \text{ for } \forall j \tag{F.8}$$

F.2.2 The algorithms

There are three important issues related to operating on Hidden Markov Models ([RODS01]):

- The Evaluation Problem. Given a HMM and a sequence of observations, calculate the probability that the HMM in question generated the sequence of observations.
- The Decoding Problem. Given a HMM and a sequence of observations, find the most probable sequence of hidden states that led to this particular sequence of observations.
- The Learning Problem. Given the structure of a HMM (number of hidden and visible states) and a set of example sequences (training set), parameterise the model (i.e. determine the matrices A, B and π).

F.2.2.1 The evaluation problem – the forward algorithm

Recalling the form of the joint probability distribution of $P(y_1^T, q_1^T)$ (eq. F.5) and marginalising for Y_1^T yields:

$$P(y_1^T) = \sum_{q_1^T} P(y_1^T, q_1^T) = P(q_1) \sum_{q_1^T} \prod_{t=1}^{T-1} P(q_{t+1}|q_t) \prod_{t=1}^{T} P(y_t|q_t) \tag{F.9}$$

where the sum is taken over all possible values of q_1^T. This gives an exponential number of terms and is therefore computationally intractable. However, calculating $P(y_1^T)$ recursively can be done in $O(c^2T)$ time, where c is the number of hidden states. To do this, we define the parameter $\alpha_t(j)$ as the probability of the partial sequence y_1^t and hidden state j at time t, given the model λ (from [RJ93], adapted to notation used in this chapter):

$$\alpha_t(j) = P(y_1^t, q_t = j|\lambda) = \begin{cases} \pi_j b_j(y_t) & t = 1 \\ [\sum_{i=1}^{c} \alpha_{t-1}(i) a_{ij}] b_j(y_t) & \text{otherwise} \end{cases} \tag{F.10}$$

Now, $P(y_1^T)$ can be calculated by taking the sum $\sum_{i=1}^{c} \alpha_T(i)$.

Implementing the recursive formula gives what is known as the *forward algorithm*:

1. **Initialise:** a_{ij}, $b_j(O_k)$, y_1^T, $\alpha_1(j)$ for $\forall\, i, j, k$
2. **for** $t \leftarrow 2$ **to** T, **for** $\forall\, j$: set $\alpha_t(j) \leftarrow b_j(y_t) \sum_{i=1}^{c} \alpha_{t-1}(i) a_{ij}$
3. **Return:** $P(y_1^T) \leftarrow \sum_{i=1}^{c} \alpha_T(i)$

F.2.2.2 The decoding problem – the Viterbi algorithm

The decoding problem may be formulated as finding the most probable sequence of hidden states, q_1^T given a sequence of observations, y_1^T. To solve this problem, one needs to assess the probability of a given state sequence at time t ending in state q_t and accounting for the partial observation sequence y_1^t:

$$\delta_t(i) = \max_{q_1,q_2,\ldots,q_{t-1}} P(q_1^{t-1}, q_t = i, y_1^T|\lambda) = \begin{cases} \pi_i b_i(y_t) & t = 1 \\ [\max_i \delta_{t-1}(i)a_{ij}]b_j(y_t) & \text{otherwise} \end{cases} \tag{F.11}$$

Implementing this formula, making use of the auxiliary array $\psi_t(j)$ to keep track of the path found so far, yields the *Viterbi algorithm*:

1. **Initialise:** a_{ij}, $b_j(O_k)$, y_1^T, $\delta_1(j)$ for $\forall\, i, j, k$
2. **for** $t \leftarrow 2$ **to** T, **for** $\forall\, j$:
   (a) set $\delta_t(j) = \max_{1\le i\le c}[\delta_{t-1}(i)a_{ij}]b_j(y_t)$
   (b) set $\psi_t(j) = \arg\max_{1\le i\le c}[\delta_{t-1}(i)a_{ij}]$
3. Set
   (a) $P^* = \max_{1\le i\le c}[\delta_T(i)]$
   (b) $q_T^* = \arg\max_{1\le i\le c}[\delta_T(i)]$
   (c) **for** $t \leftarrow T-1$ **downto** 1, set $q_t = \psi_{t+1}(q_{t+1}^*)$
4. **Return:** Optimal sequence q^* with probability P^*.

F.2.2.3 The learning problem

The estimation of parameters for Hidden Markov Models is a complicated process, and the derivation of the relevant formulas will not be treated in detail in this document. A full derivation is found in [RJ93].

First, we need to introduce the *backward variable*, β, that is defined analogous to the forward variable α (see section F.2.2.1):

$$\beta_t(j) = P(y_{t+1}^T|q_t = j, \lambda) = \begin{cases} 1 & t = 1 \\ \sum_{i=1}^c a_{ji} b_i(y_{t+1})\beta_{t+1}(i) & \text{otherwise} \end{cases} \tag{F.12}$$

In addition, the bi-variate function $\delta(y_t, v_k)$ (not related to $\delta_t(j)$ in the Viterbi algorithm) is defined as:

$$\delta(y_t, v_k) = \begin{cases} 1 & \text{if} y_t = v_k, \\ 0 & \text{otherwise} \end{cases} \tag{F.13}$$

With these variables, the estimators for the three parameters of a HMM may be stated as:

$$\begin{aligned} \bar{\pi}_i &= \frac{\alpha_0(i)\beta_0(i)}{\sum_{j=1}^c \alpha_T(j)} \\ \bar{a}_{ij} &= \frac{\sum_{t=1}^T \alpha_{t-1}(i)a_{ij}b_j(y_t)\beta_t(j)}{\sum_{t=1}^T \alpha_{t-1}(i)\beta_{t-1}(i)} \\ \bar{b}_j(k) &= \frac{\sum_{t=1}^T \alpha_t(i)\beta_t(i)\delta(y_t,v_k)}{\sum_{t=1}^T \alpha_t(i)\beta_t(i)} \end{aligned} \tag{F.14}$$

The parameters for the HMM may be calculated by repeatedly applying these formulas, using sequences y_1^T from the training set, until convergence is achieved.

F.3 The Vector Quantiser

The Vector Quantiser (VQ) is a module quantising multidimensional vectors to discrete symbols. A block diagram of a Vector Quantiser is shown in figure F.6.

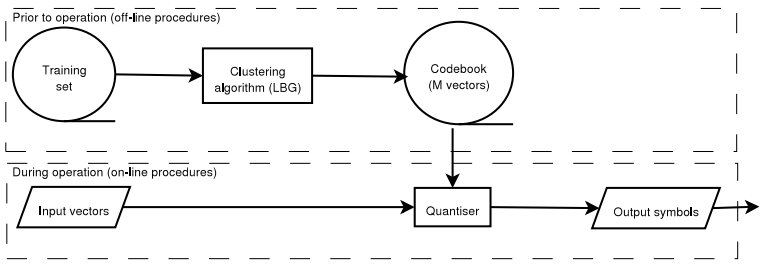


Figure F.6: Block diagram of a Vector Quantiser (inspired by the block diagram [RJ93, fig. 3.40]).

There are several algorithms for clustering, one of the more popular is the LBG algorithm. The LBG algorithm was first proposed by Linde, Buzo and Gray and generates a codebook (set of prototype vectors corresponding to discrete symbols) for a Vector Quantiser by taking an input set of training vectors and iteratively dividing these into $2, 4, \ldots, 2^m$ partitions, calculating the centroid of each partition.

The algorithm (in verbatim from [JYYX94]):

1. Initialization: Set L (number of partitions or clusters) $= 1$. Find the centroid of all the training data.
2. Splitting: Split L into $2L$ partitions. Set $L = 2L$.
3. Classification: Classify the set of training data x_k into one of the clusters C_i according to the nearest neighbor rule.
4. Codebook Updating: Update the codeword of every cluster by computing the centroid in each cluster.
5. Termination 1: If the decrease in the overall distortion D at each iteration relative to the value D for the previous iteration is below a selected threshold, proceed to Step 6; otherwise go back to Step 3.
6. Termination 2: If L equals the VQ codebook size required, stop; otherwise go back to Step 2.

A flowchart description is available in [RJ93] and shown in figure F.7.

[RJ93] list some moments of attention when designing the codebook generation routines (L is the number of training vectors, M is the size of the codebook to be generated):

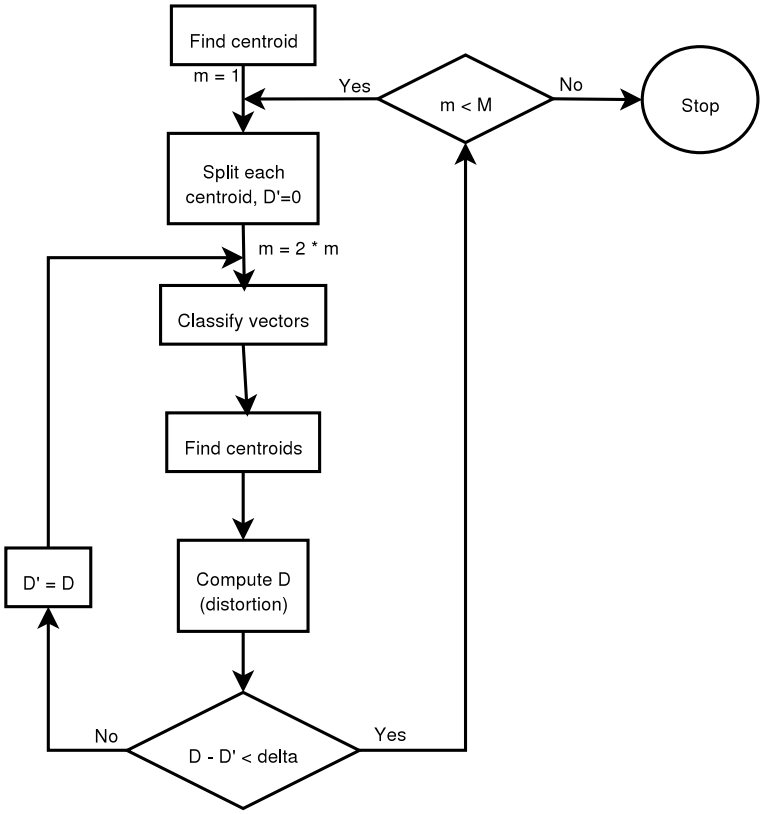


Figure F.7: Flowchart of LBG (binary split) algorithm, [RJ93, fig. 3.42].

- One will need a large set of training vectors to create a robust codebook, in general $L \gg M$. In practise, this means that $L \geq 10M$.
- A good measure of similarity between vectors. One such measure is euclidean distance, and we assume that this applies to our data, at least the positional streams.

F.4 The Short-Time Fourier Transform

The Short-Time Fourier Transform (ST-FT) of the signal $x(t)$ is defined as follows (definition from [JYYX94], rewritten to discrete form):

$$STFT_N^{\gamma}(x,t,k) = \sum_{t'=0}^{N} [x(t')\gamma^*(t'-t)]e^{\imath\frac{-2\pi k t'}{N}} \tag{F.15}$$

Here, $\gamma^*(t'-t)$ represent a shifted analysis window centred around t. The ST-FT can be implemented as a Fast Fourier Transform (FFT) just like the ordinary FT, by using the transformation:

$$\begin{aligned} STFT_N^{\gamma}(x,t,k) &\stackrel{\text{def}}{=} \textstyle\sum_{t'=0}^{N}[x(t')\gamma^*(t'-t)]e^{\frac{-2\imath\pi k t'}{N}} \\ &= \textstyle\sum_{y=0}^{N/2-1}[x(2y)\gamma^*(2y-t)]e^{-\imath\frac{2\pi k(2y)}{N}} \\ &\quad + \textstyle\sum_{y=0}^{N/2-1}[x(2y+1)\gamma^*((2y+1)-t)]e^{-\imath\frac{2\pi k(2y+1)}{N}} \\ &= \textstyle\sum_{y=0}^{N/2-1}[x(2y)\gamma^*(2y-t)]e^{-\imath\frac{2\pi k(2y)}{N}} \\ &\quad + e^{-\imath\frac{2\pi k}{N}} \textstyle\sum_{y=0}^{N/2-1}[x(2y+1)\gamma^*((2y+1)-t)]e^{-\imath\frac{2\pi k(2y)}{N}} \\ &= STFT_{N/2}(x_{\text{even}},t,k) + e^{-\imath\frac{2\pi k}{N}} STFT_{N/2}(x_{\text{odd}},t,k) \end{aligned} \tag{F.16}$$

This means the ST-FT can be calculated recursively, reducing asymptotic time complexity from $O(n^2)$ to $O(n \log n)$. Note that the above calculation splits the data in two, forcing window sizes to be a power of two. It is possible to perform an analogous calculation dividing by the smallest prime factor.

Appendix G

5DT Data Glove 5: Technical details

This appendix provides technical details on 5DT Data Glove 5, consisting of resolution of output data, computer interface, data transfer and basic driver functions.

Resolution

The flexure sensors are built upon a proprietary fiber optic technology, and has 8-bit resolution, which yields a total of 256 positions. The tilt sensors has an accuracy of 0.5 °, and a range spanning from −60 ° to 60 °. The resolution for the tilt sensors is also 8-bit.

Computer Interface

1. RS 232, 3-wire(GND,TX,RX) (regular PC serial interface)
2. Transfer rate: 19200 bps
3. 8 data bits, 1 stop bit, no parity, no handshaking.

Power Supply

Maximum 150 mA @ 9V DC

Sampling Rate

200 samples per second

G.1 Data transfer

The *5DT Data Glove 5* uses packets to transfer sensor data. It has a set of control commands to initiate different states. Data stream mode is used when a continuous stream of sensor data is wanted. It is initiated with ASCII character D. The stream sent from the glove consists of packets of fixed length. The data packets has a header, which is one byte long, and always has the value $0x80$. The header is followed by five bytes with sensor data, one byte for each finger. Right hand gloves transfer data for the thumb first, and the little finger last. Left hand gloves transfer data from little finger first, and thumb last. When the five finger sensor data packets are transferred, one byte of data from each of the pitch and roll sensors are transferred. When a mouse is in emulation mode, a different packet structure is transferred. Packets then consist of three bytes, and a packet is only sent when there is a change in the values. The packet consists of two two's complement numbers of 8 bits describing the change in X and Y position since the last packet. It also has two bits for the left and right mouse buttons.

G.2 Driver functions

```
fdGlove *fdOpen(char *pPort)
```

Initializes the glove connected to port specified by pPort. Returns a pointer to the glove device. Returns NULL in case of error.

```
int fdClose(fdGlove *pFG)
```

Closes the communication port and disconnects the glove.

```
void fdGetSensorScaledAll(fdGlove *pFG, float *pData)
```

Obtains the most recently scaled sensor values from the glove specified by pFG. Scaling is done with respect to auto-calibrations routines performed by the driver. The size of the pData array must match the value of fdGetNumSensors(). Scaled values defaults to range [0...1].

```
int fdGetGesture(fdGlove *pFG)
```

Returns the current gesture being performed.

Appendix H

Flock of Birds: Technical details

This appendix provides technical details on the motion tracking system *Flock of Birds*. It consists of the basic commands and technical specifications of the hardware.

H.1 The basic commands

When we are using the RS-232 interface between host computer and master unit, we have many commands available. Below follows a list of the basic RS-232 commands.

- POSITION, ANGLES, MATRIX, QUATERNION: Specifies the kind of output we will get from a given bird, also called data records.

  - POSITION: X, Y and Z coordinates of the sensor.
  - ANGLES: 3 rotation angles, around each of the axes.
  - MATRIX: A 9-element rotation matrix.
  - QUATERNION: Quaternions.

  There are also commands like POSITION/ANGLES that makes the output a composite data record.

- CHANGE/EXAMINE VALUE: Changes or examines a bird's system parameter.
- FBB RESET: Resets all the slaves on the FBB.
- POINT: Makes a specific bird respond with its output. If the flock is in group mode, all flock units respond simultaneously.
- REFERENCE FRAME: Defines the reference frame in which measurements are made.
- RS232 TO FBB: Talk to all birds on the FBB via one RS232 interface.
- RUN/SLEEP: Turns on/off a transmitter.

- STREAM/STREAM STOP: Makes the birds start or stop delivering measurements continuously.

FBB commands (used on the Fast Bird Bus) are listed below. These commands are

- FBB RS232CMD: Used when a bird on the FBB wants to issue a RS-232 command. RS-232 commands which are valid on the FBB are listed in the *Flock of Birds* documentation.
- FBB SEND DATA: When a bird receives this command, it outputs a data record.
- FBB SEND STATUS: When a bird receives this command, it returns its operational status.
- FBB SEND ERROR CODE: When a bird receives this command, it returns a representation of the first error it has encountered.

H.2 Technical specifications

Optimal distance from transmitter to sensor
(this distance guarantees 20-144 measurements per second):
- With standard transmitter: <= 4 feet
- With extended range transmitter: <= 8 feet
Range of the sensor's orientation:
- ± 180° Azimuth & Roll
- ± 90° Elevation
(Azimuth, Elevation and Roll are rotations about the Z, Y and X axis, respectively.)
Static positional accuracy: 0.07" RMS
Positional resolution: 0.03" at 12" distance
Static angular resolution: 0.1° RMS
Angular resolution: 0.1° RMS at 12" distance
Update rate: 100 measurements/sec
Outputs: X, Y, Z positional coordinates & orientation angles, rotation matrix, or quaternions
Interface:
-RS232: 2,400 to 115,200 baud
-RS485: 57,600 to 500,000 baud
Format: Binary
Modes: Point or stream(RS232 only)

Enclosed with the system are drivers that allow you to run the *Flock of Birds* through a RS-232C interface, and a command line menu tool that lets you issue commands from a menu and observe the output on the screen.

Appendix I

Abbreviations and terms

Abbreviations used in the SRS for long terms are summarized in this section. This list is standardized as; <abbreviation> <Name.> <Explanation.>, whereas the explanation part is only present if it is appliccable.

Glisa Glove is in the Air. The name of the project.

GUI Graphical User Interface. The part of a program that is displayed to the user.

NTNU Norwegian University of Technology and Science.

SRS Software Requirements Specification. The document that defines requirements for a software project.

USB Universal Serial Bus. A fast serial bus interface.

VR Virtual Reality.

VTK Visualisation Toolkit. A graphics package from Kitware.

Appendix J

File format specifications

This appendix describes the file formats used by *Glisa*.

J.1 `glisa.xml` specification

`glisa.xml` is the main configuration file for *Glisa*, and is an XML-document conforming to the Document Type Definition shown in code listing J.1.1.

Code Listing J.1.1 (Document Type Definition for glisa.xml)

```
<!ELEMENT calibrate ( cam_position, cam_clipping_range, cam_focal_point,
                      win_size ) >
<!ELEMENT cam_clipping_range ( min, max ) >
<!ELEMENT cam_focal_point ( x, y, z ) >
<!ELEMENT cam_position ( x, y, z ) >
<!ELEMENT control ( postures ) >
<!ELEMENT flock_of_birds ( port, nof_sensors ) >
<!ELEMENT gesture_path ( #PCDATA ) >
<!ELEMENT gesture_recogniser ( gesture_path, hmm ) >
<!ELEMENT glisa ( control, input3d, mouse, gesture_recogniser, calibrate,
                  inputinterface ) >
<!ELEMENT glove ( port, sensor ) >
<!ELEMENT hmm ( quantiser_resolution, states, reduction_factor ) >
<!ELEMENT index_finger ( min, max ) >
<!ELEMENT input3d ( postures ) >
<!ELEMENT inputinterface ( glove+, flock_of_birds, samplingrate ) >
<!ELEMENT little_finger ( min, max ) >
<!ELEMENT max ( #PCDATA ) >
<!ELEMENT middle_finger ( min, max ) >
<!ELEMENT min ( #PCDATA ) >
<!ELEMENT mouse ( postures ) >
<!ELEMENT nof_sensors ( #PCDATA ) >
<!ELEMENT port ( #PCDATA ) >
<!ELEMENT posture ( thumb, index_finger, middle_finger, ring_finger,
                    little_finger ) >
<!ATTLIST posture name NMTOKEN #REQUIRED >
<!ELEMENT postures ( posture+ ) >
<!ELEMENT quantiser_resolution ( #PCDATA ) >
<!ELEMENT reduction_factor ( #PCDATA ) >
<!ELEMENT ring_finger ( min, max ) >
<!ELEMENT samplingrate ( #PCDATA ) >
<!ELEMENT sensor ( #PCDATA ) >
<!ELEMENT states ( #PCDATA ) >
<!ELEMENT thumb ( min, max ) >
<!ELEMENT win_size ( x, y ) >
<!ELEMENT x ( #PCDATA ) >
<!ELEMENT y ( #PCDATA ) >
<!ELEMENT z ( #PCDATA ) >
```

J.2 `gesture_db.xml` specification

`gesture_db.xml` is the gesture data base for the gesture recognizer, and is an XML-document conforming to the Document Type Definition shown in code listing J.2.1.

Code Listing J.2.1

```
<!ELEMENT description ( #PCDATA ) >
<!ELEMENT filename ( #PCDATA ) >
<!ELEMENT gesture ( name, description, filename ) >
<!ELEMENT gesturedb ( gesture ) >
<!ELEMENT name ( #PCDATA ) >
```

Appendix K

Usability test tasks

This usability test are split into two main parts. One for testing the gesture training application and one for testing the demo application of Glisa.

K.1 Gesture training application usability test

The gesture training application is an application for training of new gestures and testing of existing gestures. A gesture is a pattern that you do with one of your hands for instance making a circle or an L. A gesture is performed by flexing all fingers except the thumb, which shall be stretched out and making a pattern. When done, flex your thumb or stretch the other fingers.

The tasks to be carried out are listed in table K.1 below:

Task id	Task	Expected result	Results
1	Calibrate the system.	User grabs for seven seconds when start grabbing is displayed on the screen until stop grabbing is displayed. Then pick the eight corners of the cube that appears in the given order.	Users did not know how much to grab and thereby had some problems with selecting the boxes.
2	Find out which gestures that are already present in the system.	Press the *Available Gesture* button.	Fairly usable, but two of the test persons struggled because they did not know what to look for.
3	Edit a gesture by either changing it's name and/or the description and save the change.	Double click a cell, make a change, press enter, then save changes.	Two persons got it right, one failed. The problem here was the fact that you have to press enter after editing and then save.
4	Delete a gesture, random of choice.	Type in the gesture name and press delete.	One person selected the cell in the table with the gesture and then pressed delete. The other persons got it right.
5	Test an existing gesture.	Press the *Test Gesture* button, then press the *Test* button and start testing gestures.	This worked well for all users.
6	Add a new gesture with the name *L*. This gesture should be a L movement with your hand. Give the gesture a proper description (i.e. Down and right) and start training the gesture. When satisfied with the training, press the *done* button.	Write name and description in text-fields, press *Perform Gesture* and train gesture.	The users managed to do this quite well.
7	Close the gesture training application.	Click the upper right corner of the application.	No problem for any of the users.

Table K.1: Usability test for gesture training application

K.2 Demo application usability test

The demo application is an application that shows the functionality of the underlying system, *Glisa*. This is a 3D application which supports interaction with 3D objects with data gloves as input device.

The tasks to be carried out are listed in table K.2 below:

Task id	Task	Expected results	Results
1	Calibrate the system.	User grabs for seven seconds when start grabbing is displayed on the screen until stop grabbing is displayed. Then pick the eight corners of the cube that appears in the given order.	Users did not know how much to grab and thereby had some problems with selecting the boxes. People also struggled to understand that this application is made to map virtual and physical space.
2	Select a box. The posture for selecting is flexing the thumb and the index finger.	The user should bring the cursor into a box and select it.	Easy to use and understand, but one participant did not realize at first that the cursor had to be inside the box.
3	Grab a box, move it and release it. The posture for grabbing is flexing all fingers, while releasing is done by extending your fingers.	The user should bring the cursor into a box, grab it, move it to another position and release it.	Intuitive and good posture, easy to do.
4	Change system mode to 2D mode. The posture for 2D mode is index- and middle finger fully stretched while flexing the others. While in 2D mode click about and click OK. The posture for clicking is flexing and releasing of the index finger.	The user should enter 2D mode, click about and OK.	Intuitive and good posture, easy to do.
5	Change back to 3D mode. The posture for 3D mode is flexing ring and little finger while stretching out the others.	The user should enter 3D mode.	Everyone managed to do this quite easily.
6	Rotate all the boxes. The posture for rotation is flexing thumb, middle- and ring finger, while stretching index- and little finger.	The user should rotate all boxes, which actually is a camera rotation.	Everyone did this on the first go. Not very intuitive, but worked well.
7	Select more than one box. The posture for selecting several boxes is flexing thumb and middle finger, while stretching the others. Do this with both hands. Your hands will then mark the diagonal corners of a selection cube. By releasing the posture the boxes are selected.	The user should span out the selection box and mark more than one box.	Very difficult, only one participant managed to do it.
8	Now perform the gesture you trained in the gesture training application. This will reset the camera position.	The user should perform the gesture he/she trained in the gesture training application.	Everyone managed to do this properly after two or three tries. The gesture recognition rate was thereby OK.

Table K.2: Usability test for demo application

K.3 Package demo

```
This is an example application of how Glisa can be used in VR applications.

The demo application consists of the following components:
    demoapp: Instatiate this class to start the application.
    graphics: Opens and renders the VTK scene.
    objects: Graphical objects used by the graphics module.
```

K.3.1 Modules

- **graphics**: Graphical part of the Demo Application for Glisa.
  (Section K.4, p. 249)
- **objects**: Objects that can be rendered in a scene.
  (Section K.5, p. 254)

K.4 Module demo.graphics

Graphical part of the Demo Application for Glisa.

A simple 3D scene is displayed where the user can select objects.

class GraphicsModule: Renders a 3D scene.

K.4.1 Variables

Name	Description
__revision__	**Value:** 2 *(type=int)*

K.4.2 Class GraphicsModule

```
Renders the 3D scene and receives input.

The class opens a VTK window and renders a simple 3D scene displaying
5 small boxes. Inputs from the user is used to control to pointer
indicators, one for each hand, and to do selection of the boxes.

Statics:
    MAX_SELECTION_DISTANCE: The maximum distance the two index fingers can be
        apart, in order to enter selection box mode. In world coordinates.
```

```
Data:
    _left_hand: The left hand pointer object. Instance of Pyramid.
    _right_hand: The right hand pointer object. Instance of Pyramid.
    _renderer: The vtkRenderer that renders the scene.
    _renWin: The vtkRenderWindow that displays the scene.
    _collection: A list containing all non-pointer objects
        in the scene.
    _last_selected: Points to the last selected object in the scene.
    _last_color: The original color of the last selected object.
    _camera_inverse: The inverse transformation matrix for the camera.
    _grabbed_right: The object currently grabbed with the right hand.
    _grabbed_left: The object currently grabbed with the left hand.
    _closed: Boolean, tells if the close() method has been called.
    _navigating: Boolean, tells if the system is in navigation mode.
    _navigation_start_position: Position of the hand when the navigation
        posture was performed.
    _camera_last_position: Last position of the camera before navigation.
    _frame_rate: Number of frames to render per second.
    _frame_length: Length in seconds of each frame.
    _total_elevation: Cummulative elevation on the camera.
    _selection_box_mode: Tells if the system is in selection box mode.
    _session_elevation: How much the camera is elevated in current
        navigation session.
    _right_index_extended: Tells if the index finger on the right hand is
        currently extended.
    _left_index_extended: Tells if the index finger on the left hand is
        currently extended.
    _last_left_transform: The last transform matrix received from the
        middleware for the left hand.
    _last_right_transform: The last transform matrix received from the
        middleware for the right hand.
    _lines: A list of lines that should be drawn in the scene.

Methods:
    __init__(): Opens the window and generates the 3D scene.
    set_left_hand_position(transform_matrix): Sets the location and
        direction of the left pointer indicator.
    set_right_hand_position(transform_matrix): Sets the location and
        direction of the right pointer indicator.
    select_object(transform_matrix): Selects an object at the specified
        position.
    grab_right_hand(transform_matrix): Grabs an object with the right hand
    grab_left_hand(transform_matrix): Grabs an object with the left hand
    release_right_hand(): Release any object previously grabbed with the
        right hand
    release_left_hand(): Release any object previously grabbed with the
        left hand
    move_camera(transform_matrix): Moves the camera according to the given
        camera transformation
    extend_right_index(transform_matrix): Tells the system that the index
        finger on the right hand is extended.
    extend_left_index(transform_matrix): Tells the system that the index
        finger on the left hand is extended.
```

```
    start_navigation(transform_matrix): Puts the system in navigtaion mode.
    stop_navigation(): Ends the navigation mode.
    start(): Starts the rendering thread.
    close(): Stops the rendering thread.
    select_right(): The right hand is doing the selection box posture.
    deleselect_right(): The right hand is no longer doing the selection box
        posture.
    select_left(): The left hand is doing the selection box posture.
    deselect_left(): The left hand is no longer doing the selection box
        posture.
    connect_selected(): All selected objects are connected with lines.
    about(): Display a pretty about box.


Non-public methods:
    _compute_transform(transform_matrix): Computes
        the transformation relative to the world coordinate
        system. Normalizes the rotation vectors.
    _within_bounds(actor, position): Determines if the specified
        position is within the actors bounds.
    _find_closest(actor_list, position): Find the actor in the
        list that has its origion closest to the specified position.
    _compute_inverse_camera_transform(camera): Finds the inverse transform
        of a vtk camera.
    _create_line(actor1, actor2): Creates a line between 2 actors.
```

K.4.2.1 Methods

__init__(*self*)

Create the window and scene.
Initialize all member attributes. Opens a QApplication that displays the scene. The QApplication exec_loop is started in a new thread.

about(*self*)

Display an about box.

close(*self*)

Close the thread that renders the scene.

connect_selected(*self*)

Create a line between the currently selected actors

deselect_left(*self*)

Marks that the left hand is no longer doing the selection box posture.
If the system was in selection box mode, all objects within the box will be selected and the system exits selection box mode.

deselect_right(*self*)

Marks that the right hand is no longer doing the selection box posture.
If the system was in selection box mode, all objects within the box will be selected and the system exits selection box mode.

grab_left_hand(*self*, *transform_matrix*)

Grab an object with the left hand.
If an object is allready selected, and the specified position is within that object's bounds, the object is selected.
Keyword arguments: transform_matrix — The transform matrix that descibes the position where grabbing is performed.

grab_right_hand(*self*, *transform_matrix*)

Grab an object with the right hand.
If an object is allready selected, and the specified position is within that object's bounds, the object is selected.
Keyword arguments: transform_matrix — The transform matrix that descibes the position where grabbing is performed.

move_camera(*self*, *transform_matrix*)

Move the camera according to the transform given as parameter.
Rotates the camera around the focal point if the transform indicates movement along the x-axis or y-axis.

release_left_hand(*self*)

Release any object currently grabbed with the left hand.

release_right_hand(*self*)

Release any object currently grabbed with the right hand.

reset_camera(*self*)

Reset the camera position to its original position.

select_object(*self*, *transform_matrix*)

Select the object at the specified position.
The method selects the object with center closest to the specified position if the position is within that object's bounding box. If the position is not within the closest object' s bounding box, no selection is made.
Keyword arguments: transform_matrix – Matrix that describes the viewport transform on the pointer indicator that does the selection. The transform is applied to the original transform, which is identity. Must be a 4x4 matrix of type NumArray.

selection_left(*self*)

Called when the right hand does the selection box posture.
If the system detects that both hands does the posture, a selection box is created.

selection_right(*self*)

Called when the right hand does the selection box posture.
If the system detects that both hands does the posture, a selection box is created.

set_left_hand_position(*self*, *transform_matrix*)

Set the position and angle of the left hand pointer indicator.
In the 3D scene, a pyramidic pointer is displayed to indicate where the left hand is positioned. It also indicates the angle in which the hand is held.
Keyword arguments: transform_matrix – Matrix that describes the new viewport transform on the pointer indicator. The transform is applied to the original transform, which is identity. Must be a 4x4 matrix of type NumArray.

set_right_hand_position(*self*, *transform_matrix*)

Set the position and angle of the right hand pointer indicator.
In the 3D scene, a pyramidic pointer is displayed to indicate where the right hand is positioned. It also indicates the angle in which the hand is held.
Keyword arguments: transform_matrix – Matrix that describes the new viewport transform on the pointer indicator. The transform is applied to the original transform, which is identity. Must be a 4x4 matrix of type NumArray.

start(*self*)

Display the window, and start rendering.
This method starts a new thread, which can be stopped by calling the method close().

start_navigation(*self*, *transform_matrix*)

Enter navigation mode.
After this method is called, move_camera() will be called each time set_right_hand_position() is called.
Keyword arguments: transform_matrix – The position and rotation specified by the transform is a starting point for navigation. The camera is moved according to how the hand is moved relative to this position.

stop_navigation(*self*)

Stop the navigation.

K.4.2.2 Class Variables

Name	Description
MAX_SELECTION_DISTANCE	**Value:** `1` *(type=**int**)*

K.5 Module demo.objects

Objects that can be rendered in a scene.

class Pyramid: A pyramid shaped object that represents the pointer devices. class CubeAssemply: A collection of cubes. class Cube: A cube shaped object used in the scene. class SelectionBox: A box that can be used to indicate selection.

K.5.1 Variables

Name	Description
__revision__	**Value:** `2` *(type=**int**)*

K.6 Package glisa

```
Glove IS in the Air - a library for data-glove user interaction.

Glisa collects data from positioning devices and data gloves and presents
this data to an application through an event based interface. There is
also recognition of finger postures (based on configurations of flexed and
straight fingers) and hand gestures (based on movement of the hand). The
user may also use the gloves to control the mouse pointer.
```

```
Usage of Glisa is through the middleware library, which provides input
support and posture/gesture recognition, the calibration application, which
establishes a mapping between the physical and virtual spaces, and the
gesture training application, which enables training and testing of
gestures, as well as gesture database maintenance. See the documentation in
the respective packages for more information.

Development with Glisa typically starts with the calibration application,
see the module glisa.calibrator, before the library itself is used for input,
see the module glisa.middleware.

Quick-start "tutorial":
    # Initialise library with a given initialisation file
    self.glisa_control = glisa.middleware.control.Control("glisa.xml")
    # Listener that recepts error messages and status change notifications.
    self.glisa_control.add_glisa_listener(self)

    # Start the event distribution (needed by the calibration application)
    thread.start_new_thread(glisa.middleware.control.Control.
                            run_event_loop, (self.glisa_control, ))

    # Create a calibration application that receives input from glisa_control
    calibrator = glisa.calibrator.calibrate.CalibrationApplication()
    self.glisa_control.get_input3d().add_input3d_listener(calibrator)

    # Perform calibration, and deactivate calibration application
    calibration_matrix = calibrator.calibrate()
    self.glisa_control.set_calibration_matrix(calibration_matrix)
    self.glisa_control.get_input3d().remove_input3d_listener(calibrator)

    # Setup application for reception of input events, and all postures
    self.glisa_control.get_input3d().add_input3d_listener(self)
    self.glisa_control.get_gesture_recogniser().add_gesture_listener(self)

    # Go, go, go!
    self._run()

    # Shutdown sampling and event distribution, and exit
    self.glisa_control.close()
    sys.exit(0)

In this package, and all subpackages, files/modules with names ending in
_test are unit test fixtures. Running the tests are done by executing the
script test.py in the main source directory of the Glisa distribution.

This library was initially developed at the Norwegian University of
Science and Technology (NTNU, http://www.ntnu.no/) August-November 2004,
as part of subject "TDT4290 Customer Driven Project" for the
Chemometry and Bioinformatics Group at the Institute of Chemistry.

Initial developers:
    Erik Rogstad
    Frode Ingebrigtsen
```

Lars-Erik Bjørk
Stein Jakob Nordbø
Trond Valen
Øyvind Bø Syrstad

K.6.1 Modules

- **calibrator**: Calibration application.
  (Section K.7, p. 256)
  - **calibrate**: This is the calibration application for Glisa.
    (Section K.8, p. 257)
- **gesttraining**: Gesture training application.
  (Section K.9, p. 258)
- **middleware**: Glisa middleware is a layer making the data from the device drivers available at a higher level.
  (Section K.10, p. 258)
  - **control**: Glisa control module.
    (Section K.11, p. 259)
  - **gestrec**: Glisa gesture recogniser module.
    (Section K.12, p. 260)
  - **input3d**: Managing virtual gloves as input devices in three dimensions.
    (Section K.13, p. 263)

K.7 Package glisa.calibrator

Calibration application.

This package contains a VTK-based application to establish a mapping between the physical and virtual spaces by letting the user span a parallelepiped in the space in front of him/her that maps to a cube in virtual space. An application using Glisa would typically run this application by its main method calibrate() prior to making use of any output from the library. The matrix returned from this method is supposed to be used as argument to glisa.middleware.Control.set_calibration_matrix(matrix).

K.7.1 Modules

- **calibrate**: This is the calibration application for Glisa.
  (Section K.8, p. 257)

K.8 Module glisa.calibrator.calibrate

```
This is the calibration application for Glisa. The result from this
application is a 4x4matrix describing the mapping between the
virtual and physical space.
class CalibrationApplication renders the 3D scene and offers the calibration
 method

class CalibrationApplication: Lets the user create a mapping between physical
and virtual space.
class CubeSphereActor: A cube that can be added to a VTK scene.
```

K.8.1 Variables

Name	Description
__revision__	**Value:** `1` *(type=int)*

K.8.2 Class CalibrationApplication

```
Renders the 3D scene and receives input.  A simple 3D scene
containing eight cubes is displayed. The user shall pick cubes in
a predefined order to make the input coordinates for the
calibration.

Methods:
__init__(): Initializes the calibration application.
calibrate(): Displays the window and starts the calibration procedure.
input_event(event): Called when an event has been detected.

Non-public methods:
_start_picking(): Displays a text in the calibration window.
_change_active(): Changes the active cube.
_init_cubes(): Creates the scene with the 8 cubes.
_find_active_cube(): Finds the cube that is currently active.
_get_text(): Extracts text from a XML node list.
_start_grabbing(seconds): Informs the user to start grabbing. Then waits a
    couple of seconds.
_stop_grabbing(seconds): Informs the user to stop grabbins. Then waits a
    couple of seconds.
```

K.8.2.1 Methods

__init__(*self*, *config_file*=None)

This constructor initializes the eight cubes, an instance of vtk.vtkLandmarkTransform, an instance of vtk.vtkRenderer and an instance of vtk.vtkRenderWindow, if given in the constructor it reads an XML configfile to set the camera position, camare focal point, camera clipping-range and the window size.

Overrides: glisa.middleware.input3d.Input3DListener.__init__

calibrate(*self*)

Renders the window and loops until all calibration points are picked by the user. The method will then return a matrix respresented as a nested list

input_event(*self*, *event*)

Called when an event is detected from the input devices.
Implemented from Input3DListener. If the event is a pick event the calibration thread is notified and the transform matrix for the event is stored.

Overrides: glisa.middleware.input3d.Input3DListener.input_event

K.9 Package glisa.gesttraining

Gesture training application.

This package contains the gesture training and testing application, a QT application that allows a user to train a new gesture, test existing gestures and edit the gesture database.

K.10 Package glisa.middleware

```
Glisa middleware is a layer making the data from the device drivers
available at a higher level.

An application interfacing the Glisa library typically instantiates a
Control object:
    my_control = glisa.middleware.Control
This object sets up the hardware from the initialisation data given in
the Glisa configuration file, by default /etc/glisa/glisa.xml on Unix-like
systems.

Getting access to the data is done through the event-interfaces:
    glisa.middleware.input3d.Input3DListener
    glisa.middleware.gestrec.GestureListener
```

```
by adding a listener implementation to the respective instances:
    my_control.get_input3d().add_input3d_listener(my_input_3d_listener)
    my_control.get_gesture_recogniser().add_gesture_listener(my_gest_list)

Then, event distribution is initiated in a thread of its own:
    thread.start_new_thread(glisa.middleware.control.Control.run_event_loop,
                            (my_control, ))
or run as often as desired:
    my_control.distribute_events()
The event thread can be terminated by calling:
    my_control.stop_event_loop()
but the sampling will continue. For a full stop in sampling (as when the
application exits) is done using my_control.close().

Data may also be polled, using
    my_control.get_input3d().get_position()
    my_control.get_input3d().get_angles()
    my_control.get_input3d().get_flexures()
for position data, euler angles and finger flexures, respectively. Beware
that these methods raise ValueError exceptions if no data has been gathered
yet.

The middleware consists of the following components:
    control: Control of data flow and mode of operation.
    input3d: Generation of input events in 3d space, and postures.
    mouse:   Moves the mouse pointer using the gloves.
    postrec: Posture recogniser.
    gestrec: General gesture recongniser framework.
    hmm:     Hidden Markov Model gesture recognition.
    winsys:  Bindings to windowing system (used by mouse emulator)

Only control, input3d and gestrec are intended to be imported by programs
utilising Glisa.
```

K.10.1 Modules

- **control**: Glisa control module.
  (Section K.11, p. 259)
- **gestrec**: Glisa gesture recogniser module.
  (Section K.12, p. 260)
- **input3d**: Managing virtual gloves as input devices in three dimensions.
  (Section K.13, p. 263)

K.11 Module glisa.middleware.control

```
Glisa control module.
```

```
This is the public interface to the Glisa library, and it supports adding
event listeners and running event distribution, both in blocking and
non-blocking modes (for multi- and single-threaded applications,
respectively).

Classes:
    Control: Glisa control class and application interface.
```

K.11.1 Variables

Name	Description
__revision__	**Value:** `0` *(type=int)*

K.12 Module glisa.middleware.gestrec

```
Glisa gesture recogniser module.

This module contains classes for general gesture recognition, and event
distribution of GestureEvents.

Classes:
    GestureEvent: Event class for gesture notifications.
    GestureListener: Listener interface for GestureEvents.
    GestureRecogniser: Base class for Glisa gesture recognisers.
```

K.12.1 Variables

Name	Description
__revision__	**Value:** `1` *(type=int)*

K.12.2 Class GestureEvent

```
An event describing the occurrence of a gesture.

Fields:
    gesture: Name of the identified gesture (string).
    certainty: Certainty with which the gesture was recognised (float
               in the range [0.0, 1.0]).
```

K.12.2.1 Methods

__init__(*self*)

K.12.3 Class GestureListener

Known Subclasses: GestureRecogniserTest

```
Listener interface for GestureEvents.

Classes that intend to receive GestureEvents should inherit this class
and override its method. The implementation in this class raises a
NotImplementedError.

Methods:
    gesture_event(event): Event handler for GestureEvents.
```

K.12.3.1 Methods

__init__(*self*)
Empty constructor, for completeness.

gesture_event(*self*, *event*)
Event handler for GestureEvents. This method is invoked on all registered listeners when a gesture is generated in 3D input mode. The event parameter is a GestureEvent instance, and the method is not supposed to return any value.

K.12.4 Class GestureRecogniser

Known Subclasses: TestRecogniser

```
Abstract gesture recogniser for Glisa.

This class handles event distribution and has a number of abstract methods
that must be overriden to provide the gesture recognition itself, allowing
for easy changing of machine learning strategies.

Implemented methods:
    add_gesture_listener(listener, gesture): Add listener for reception of
```

```
        events concerning gesture.
    remove_gesture_listener(listener [,gesture]): Remove listener.
    process_samples(samples): Process samples and recognise gestures.
    train_gesture(name, description, gesture_data): Train a new gesture.
    change_gesture(old_name, new_name, new_description): Change a gesture.
    list_gestures(): List all registered gestures, with descriptions.
    _write_gesture_db(): Write gesture database to file.
    _construct_db(): Read gesture database from file.
Abstract methods:
    _handle_specific(name, data): Read in a gesture based on data returned
        from _train().
    _recognise(positions): Perform the actual recognition.
    _train(name, gesture_data): The actual training.
    _remove(name): Remove a gesture from further recognition.
```

K.12.4.1 Methods

__init__(*self*, *gestrec_dom*=`None`)

Setup, from XML if possible.

add_gesture_listener(*self*, *listener*, *gesture*=`None`)

Add a listener for gesure events.
The listener is expected to be a GestureListener, and gesture is a string identifying a gesture, or None; enabling listening for all gestures. No warning is produced if the gesture identifier is unknown.

change_gesture(*self*, *old_name*, *new_name*, *new_description*)

Change a gesture name or description.

delete_gesture(*self*, *name*)

Delete a specific gesture permanently.

list_gestures(*self*)

List all registered gestures and descriptions. Returns a list of two-tuples containing (name, description).

process_samples(*self*, *samples*)

Test a sequence of samples to see if it is a gesture, and distribute events to all registered listeners.

remove_gesture_listener(*self*, *listener*, *gesture*=None)

Remove a listener, or disable listening for a certain gesture.

train_gesture(*self*, *name*, *description*, *gesture_data*)

```
Perform initial training of a gesture, and register it. If a gesture
of the same name exists, perform retraining if possible.

Parameters:
    name: String identifying the gesture.
    description: Textual description of the gesture.
    gesture_data: List of lists of Samples representing several
                  examples of the gesture.
```

K.13 Module glisa.middleware.input3d

```
Managing virtual gloves as input devices in three dimensions.

This module is responsible for creating and distributing Input3DEvents
to registered Input3DListeners when receiving samples from the Control
class. Polling of values is also supported.

Classes:
    Input3DEvent: Event-class for Input3DListener.
    Input3D: 3D input module in Glisa.
    Input3DListener: Listener interface for Input3DEvents.
```

K.13.1 Variables

Name	Description
__revision__	**Value:** 1 *(type=int)*

K.13.2 Class Input3D

```
3D input module in Glisa.

This class provides basic input events, and may also be polled
on last processed values of the different parameters.

Methods:
    add_input3d_listener(listener): Register a new listener.
    remove_input3d_listener(listener): Unregister a listener.
```

```
process_samples(samples): Generate Input3DEvents from samples.
get_position(id): Return last position.
get_angles(id): Return last rotation angles.
get_finger_flexures(id): Return finger flexure data.
```

K.13.2.1 Methods

__init__(*self*, *input3d_dom*=`None`)

Initialises listener list and last values dictionary. Also registers default postures: pick, grab, navigate.

add_input3d_listener(*self*, *listener*)

Register a listener for reception of Input3DEvents.

get_angles(*self*, *glove_id*)

Return last rotation angles. 3-tuple of floats. Raises a ValueError if no samples has been processed yet (there is no last value).

get_finger_flexures(*self*, *glove_id*)

Return last finger flexures. 3-tuple of floats. Raises a ValueError if no samples has been processed yet (there is no last value).

get_position(*self*, *glove_id*)

Return last position. 3-tuple of floats. Raises a ValueError if no samples has been processed yet (there is no last value).

process_samples(*self*, *samples*, *is_gesture*=`False`)

Process all samples and distribute events to all listeners. samples is assumed to be a list/tuple of Sample instances, and the method does not return a value. The is_gesture parameter is set to true if a gesture is currently being performed.

remove_input3d_listener(*self*, *listener*)

Unregister a listener for Input3DEvents.

K.13.3 Class Input3DEvent

```
Event class carrying information over an Input3DListener.

This class is basically a record, and all values are public. Please
note that the matrix given is in viewport space, transformed to a
unit cube. The homogenous parameter for these coordinates cannot be
assumed to be one, and thus matrix[:3, -1] is not the coordinate
tuple for the event (try matrix[:3, -1]/matrix[-1, -1] instead).

Fields:
    event_type: Type of event (move, etc.; see constants; int)
    posture: Textual identification of posture.
    gesture_active: True if a gesture is being performed.
    timestamp: System milliseconds when values were measured (long int).
    glove_id: Identifier of position sensor/glove pair (int).
    matrix: 4x4 transformation matrix (viewport(!) space).
    flexures: Finger flexures in the range [0..1] (5-tuple of float, where
              position 0 is the thumb and 5 the little finger.
```

K.13.3.1 Methods

__init__(*self*)
Set default values.

K.13.3.2 Class Variables

Name	Description
MOVE_EVENT	**Value:** 1 *(type=int)*
POSTURE_EVENT	**Value:** 2 *(type=int)*
POSTURE_RELEASE_EVENT	**Value:** 3 *(type=int)*

K.13.4 Class Input3DListener

Known Subclasses: CalibrationApplication, ControlTest, Input3DTest

```
Listener interface for Input3DEvents.

Classes that intend to receive Input3DEvents should inherit this class
and override its method. The implementation in this class raises a
NotImplementedError.
```

```
Methods:
    input_event(event): Event handler function for Input3DEvents.
```

K.13.4.1 Methods

__init__(*self*)

Empty constructor, for completeness.

input_event(*self*, *event*)

Event handler for Input3DEvents. This method is invoked on all registered listeners when an input event is generated in 3D input mode. The event parameter is an Input3DEvent instance, and the method is not supposed to return any value.

Appendix L

Glove is in the air lowlevel API

L.1 Glove is in the air: Lowlevel Hierarchical Index

L.1.1 Glove is in the air: Lowlevel Class Hierarchy

This inheritance list is sorted roughly, but not completely, alphabetically:

DataGlove . . . 268
InputSampler . . . 274
PositioningDevice . . . 277
  FlockOfBirds . . . 270
Sample . . . 279
SampleList . . . 281
SerialCom . . . 283

L.2 Glove is in the air: Lowlevel Class Index

L.2.1 Glove is in the air: Lowlevel Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

DataGlove . . . 268
FlockOfBirds . . . 270
InputSampler . . . 274
PositioningDevice . . . 277
Sample . . . 279
SampleList . . . 281
SerialCom . . . 283

L.3 Glove is in the air: Lowlevel Class Documentation

L.3.1 DataGlove Class Reference

`#include <data_glove.h>`

Public Member Functions

- **DataGlove** ()
- **~DataGlove** ()
- int **get_handedness** ()
- void **get_sensor_values** (float gloveData[5])
- void **open_glove** (char *port)

L.3.1.1 Detailed Description

Class that provides access to a 5DT Data Glove.

L.3.1.2 Constructor & Destructor Documentation

DataGlove::DataGlove () Constructor takes no arguments

DataGlove::~DataGlove () Destructor

L.3.1.3 Member Function Documentation

int DataGlove::get_handedness ()

Returns:
Handhedness defined in glove_handedness.

void DataGlove::get_sensor_values (float *gloveData*[5])

Parameters:
gloveData[5] Array where finger flexures shall be stored.

void DataGlove::open_glove (char * *port*) Opens a glove.

Parameters:

port Address of the port where the glove is connected

Returns:

0 if success, -1 if fail.

Exceptions:

std::string if it fails

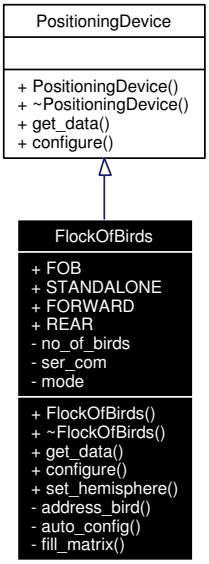
The documentation for this class was generated from the following files:

- data_glove.h
- data_glove.cpp

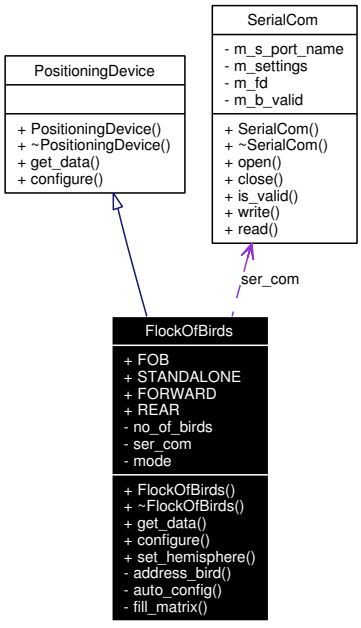
L.3.2 FlockOfBirds Class Reference

`#include <flock_of_birds.h>`

Inheritance diagram for FlockOfBirds:



Collaboration diagram for FlockOfBirds:



Public Member Functions

- **FlockOfBirds** ()
- **~FlockOfBirds** ()

- void **get_data** (int bird_address, double pos_matrix[4][4])
- void **configure** (string *ports, int no_of_ports, int no_of_birds)
- void **set_hemisphere** (int bird_address, int hemisphere)

Static Public Attributes

- const int **FOB** = 1
- const int **STANDALONE** = 0
- const int **FORWARD** = 0
- const int **REAR** = 1

L.3.2.1 Detailed Description

This class controls the Flock of Birds hardware. It configures the hardware and delivers a given sensor's position and orientation in a 4x4 transform matrix.

Author:

Trond Valen, with the exception of get_data(int, double [4][4]), which is partly written by Jahn Otto Andersen.

L.3.2.2 Constructor & Destructor Documentation

FlockOfBirds::FlockOfBirds () Constructor of this class, does nothing but instantiating member variables.

FlockOfBirds::~FlockOfBirds () Destructor of this class. Closes the serial port.

L.3.2.3 Member Function Documentation

void FlockOfBirds::configure (string * *ports*, int *no_of_ports*, int *no_of_birds*) `[virtual]`
Auto-configures the Flock of Birds to use the given number of birds, as needed. Sets forward hemisphere and data record format to be POSITION/MATRIX. This class supports only one port. The argument no_of_ports, and the ports array, is present only because this function is overriden from **PositioningDevice**(p. 277). If you use more than one bird the birds must have contiguous addresses from 1 to no_of_birds set by the dipswitches on the back panel of the bird unit. The bird with address 1 is the master.

Parameters:

ports For compatibility with the **PositioningDevice**(p. 277) interface, supply a 1-element array with the native name of the port for the Flock of Birds connection.

no_of_ports The number of ports that the Flock of Birds will use.

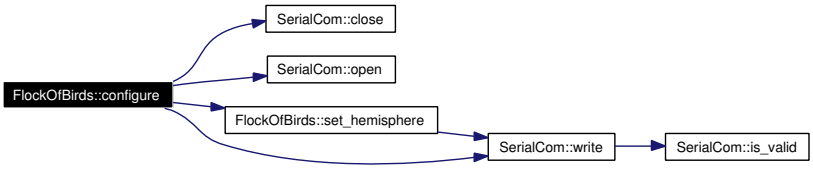
no_of_birds The number of birds you wish to use.

Exceptions:

std::string Describing the error that occured if configuring the hardware failed

Implements **PositioningDevice** (p. 277).

Here is the call graph for this function:



void FlockOfBirds::get_data (int *bird_address*, double *pos_matrix*[4][4]) `[virtual]` Turns the input matrix into a transform matrix representing the position and orientation of the bird. See to that the bird you read from is on the correct side of the transmitter. This function yields the correct data if the sensor to be read from is in the current hemisphere, see set_hemisphere.

Author:

Jahn Otto Andersen and Trond Valen

Parameters:

bird_address The FBB address of the bird whose data you want to get.

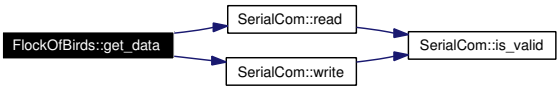
pos_matrix The data structure you want the transform matrix to be stored in.

Exceptions:

std::string Describing the error that occured if communicating with hardware failed

Implements **PositioningDevice** (p. 278).

Here is the call graph for this function:



void FlockOfBirds::set_hemisphere (int *bird_address*, int *hemisphere*) Sets the hemisphere of the Flock of Birds. Because the transmitter's magnetic field is symmetric around the transmitter,

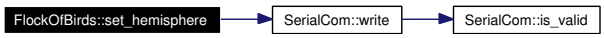
this is necessary to keep a consistent coordinate system relative to the transmitter. You can either set it to **FlockOfBirds.FORWARD**(p. 273) or **FlockOfBirds.REAR**(p. 273). REAR means you keep the sensor on the same side of the transmitter as its power cord, and FORWARD is the other side. This class does not detect hemisphere shifts, meaning you have to keep the sensor on one side of the transmitter while working.

Parameters:

bird_address The address of the bird whose hemisphere you want to set

hemisphere The hemisphere you want the bird to be in, either FORWARD or REAR.

Here is the call graph for this function:



L.3.2.4 Member Data Documentation

const int FlockOfBirds::FOB = 1 `[static]` Flock of Birds operation mode, i.e, one master unit with address set to 1, and n slaves on contiguous addrees from 2 and upwards.

const int FlockOfBirds::FORWARD = 0 `[static]` The forward hemisphere, as explained in **set_hemisphere()**(p. 272)

const int FlockOfBirds::REAR = 1 `[static]` The rear hemisphere, as explained in **set_hemisphere()**(p. 272)

const int FlockOfBirds::STANDALONE = 0 `[static]` Stand-alone operation mode, meaning only one bird is connected. This means there is no need to address the bird.

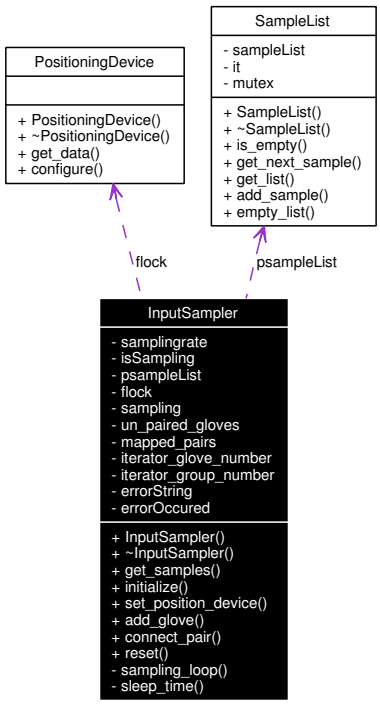
The documentation for this class was generated from the following files:

- flock_of_birds.h
- flock_of_birds.cpp

L.3.3 InputSampler Class Reference

`#include <input_sampler.h>`

Collaboration diagram for InputSampler:



Public Member Functions

- **InputSampler** ()
- ~**InputSampler** ()
- **SampleList** ∗ **get_samples** ()
- void **initialize** (int sample_rate)
- void **set_position_device** (const char ∗port, int noPorts, int noOfBirds)
- int **add_glove** (char ∗port)
- void **connect_pair** (int gloveID, int posSensorID)
- void **reset** ()

Friends

- void ∗ **set_up_thread** (void ∗ptr)

L.3.3.1 Detailed Description

A class for making samples of datagloves and positioning devices. Stacks samples in a list, witch can be accessed from other classes.

Author:
Ã152yvind BÃ184 Syrstad

L.3.3.2 Constructor & Destructor Documentation

InputSampler::InputSampler () Constructor takes no arguments

InputSampler::~InputSampler () Destructor takes no arguments

L.3.3.3 Member Function Documentation

int InputSampler::add_glove (char * *port*) Adds a glove device

Parameters:
port The port to which the glove is connected (/dev/ttySx)

Returns:
Id of the added glove

Here is the call graph for this function:

void InputSampler::connect_pair (int *gloveID*, int *posSensorID*) Connects a glove to a bird. If the glove corresponding to the gloveID does not exist, everything will work, but all fingerflexures will be 0. Similarly if birdID does not correspont to a actual bird, all positioning data will be zero.

Parameters:
gloveID Id of a glove

birdID Id of a bird

SampleList * InputSampler::get_samples () This method returns the samples sampled since last call to the method.

Returns:

A **SampleList**(p. 281) that contains all the samples aquired since last time this method was called.

void InputSampler::initialize (int *sample_rate*) Starts the sampling. When this is called, no further units can be added.

Parameters:

sample_rate Number of samples per second.

void InputSampler::set_position_device (const char * *port*, int *noPorts*, int *noOfBirds*) Sets the position device

Parameters:

port The port where the device is connected (/dev/ttySx or COMx)

noPorts Must be set to 1 for Flock of Birds. This is for future compability with other devices

noOfBird The number of birds on a positioning device. For a master and slave bird, the number is 2.

Exceptions:

a std::string if configuration of position device failed

Here is the call graph for this function:

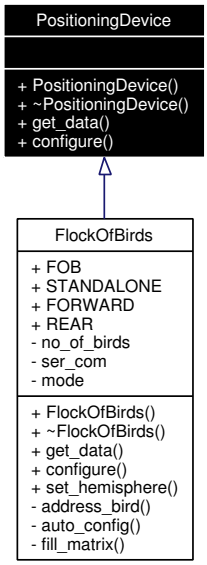
The documentation for this class was generated from the following files:

- input_sampler.h
- input_sampler.cpp

L.3.4 PositioningDevice Class Reference

`#include <positioning_device.h>`

Inheritance diagram for PositioningDevice:



Public Member Functions

- virtual void **get_data** (int id, double pos_matrix[4][4])=0
- virtual void **configure** (string *ports, int no_of_ports, int no_of_objects)=0

L.3.4.1 Detailed Description

This class represents a device used to measure position and orientation of objects in space.

L.3.4.2 Member Function Documentation

virtual void PositioningDevice::configure (string * *ports*, int *no_of_ports*, int *no_of_objects*) `[pure virtual]` This prepares the positioning device for reading and writing to the hardware. The ports argument is a string array, in case one wants to use more than one port. Any special configurations must be specified in subclasses only. Any implementations of PositioningDevice should throw exceptions in the form of c++ string if errors occur.

Parameters:

ports The names of the ports the positioning device uses.

no_of_ports The number of ports to be used.

no_of_objects The number of objects whose position/orientation is measured

Implemented in **FlockOfBirds** (p. 271).

virtual void PositioningDevice::get_data (int *id*, double *pos_matrix*[4][4]) `[pure virtual]`
Yields a 4 by 4 transform matrix, representing the position and orientation of the object labelled with the number id. Any implementations of PositioningDevice should throw exceptions in the form of c++ strings if errors occur.

Parameters:

pos_matrix The matrix in which the result will be put

id The identifier of the object whose position and orientation you want to read.

Implemented in **FlockOfBirds** (p. 272).

The documentation for this class was generated from the following files:

- positioning_device.h
- positioning_device.cpp

L.3.5 Sample Class Reference

`#include <sample.h>`

Public Member Functions

- **Sample** ()
- ~**Sample** ()
- double **get_matrix** (int i, int j)
- double **get_flexure** (int i)

Public Attributes

- int **glove_id**
- double **timestamp**

Friends

- class **InputSampler**

L.3.5.1 Detailed Description

A class that contains data from a sample. No fancy, only variables and access.

L.3.5.2 Constructor & Destructor Documentation

Sample::Sample () Constructor takes no arguments.

Sample::~Sample () Destructor

L.3.5.3 Member Function Documentation

double Sample::get_flexure (int *i*) Method to access flexure array.

Parameters:

i finger index(0=thumb,4=pinky)

Returns:
normalized flexure value.

double Sample::get_matrix (int *i*, int *j*) Method to access transformation matrix

Parameters:
i row index
j col index

Returns:
value of element

L.3.5.4 Member Data Documentation

int Sample::glove_id ID of the positioning device and gloved pair.

double Sample::timestamp Timestamp

The documentation for this class was generated from the following files:

- sample.h
- sample.cpp

L.3.6 SampleList Class Reference

`#include <sample_list.h>`

Public Member Functions

- **SampleList** ()
- ~**SampleList** ()
- bool **is_empty** ()
- **Sample** * **get_next_sample** ()
- std::list< **Sample** * > **get_list** ()
- void **add_sample** (**Sample** *s)
- void **empty_list** ()

L.3.6.1 Detailed Description

A class that provides mutex functionality for access to a std::list<Sample*>.

L.3.6.2 Constructor & Destructor Documentation

SampleList::SampleList () Constructor takes no arguments.

SampleList::~SampleList () Destructor.

L.3.6.3 Member Function Documentation

void SampleList::add_sample (Sample * *s*) Adds a sample to list.

Parameters:
s **Sample**(p. 279) to be added

void SampleList::empty_list () Emptys the list.

list< Sample * > SampleList::get_list () Returns the lists, and emptys the old.

Returns:
List

Sample * SampleList::get_next_sample () Returns the first sample in the list

Returns:
A sample

bool SampleList::is_empty () Checks if the list is empty

Returns:
true if the list is empty

The documentation for this class was generated from the following files:

- sample_list.h
- sample_list.cpp

L.3.7 SerialCom Class Reference

`#include <serialcom.h>`

Public Member Functions

- **SerialCom** (std::string sPortName)
- **~SerialCom** ()
- void **open** ()
- void **close** ()
- bool **is_valid** ()
- void **write** (char *data, int iLength)
- void **read** (char *buffer, int iLength)

L.3.7.1 Detailed Description

The SerialCom class is a class for basic rs232 communication over the serial port

Author:
Jahn Otto Andersen

L.3.7.2 Constructor & Destructor Documentation

SerialCom::SerialCom (std::string *sPortName*) Constructor

Parameters:
port The port

SerialCom::~SerialCom () Destructor

Exceptions:
std::string If the port couldn't restore its settings or be closed

Here is the call graph for this function:

L.3.7.3 Member Function Documentation

void SerialCom::close () Close the port; restore original settings and close it

Exceptions:
std::string If the port couldn't restore its settings or be closed

bool SerialCom::is_valid ()

Returns:
Whether the connection is valid

void SerialCom::open () Initialize the port; open the port and set the port settings

Exceptions:
std::string If the port initialization fails

void SerialCom::read (char * *buffer*, int *iLength*) Read data from the serial port

Parameters:
buffer The buffer in which to place the read data
iLength The desired data length

Returns:
The number of bytes read

Exceptions:
std::string If the read fails

Here is the call graph for this function:

void SerialCom::write (char * *data*, int *iLength*) Write data to the serial port

Parameters:
data The data to be written

iNumBytes The data length (number of bytes)

Exceptions:

std::string If data couldn't be written

Here is the call graph for this function:

The documentation for this class was generated from the following files:

- serialcom.h
- serialcom.cpp

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